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Hanford 200 Areas Spectral Gamma Baseline Characterization Project

B-BX-BY WMA and Adjacent Waste Sites Summary Report

For External Review Only

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Grand Junction, Colorado

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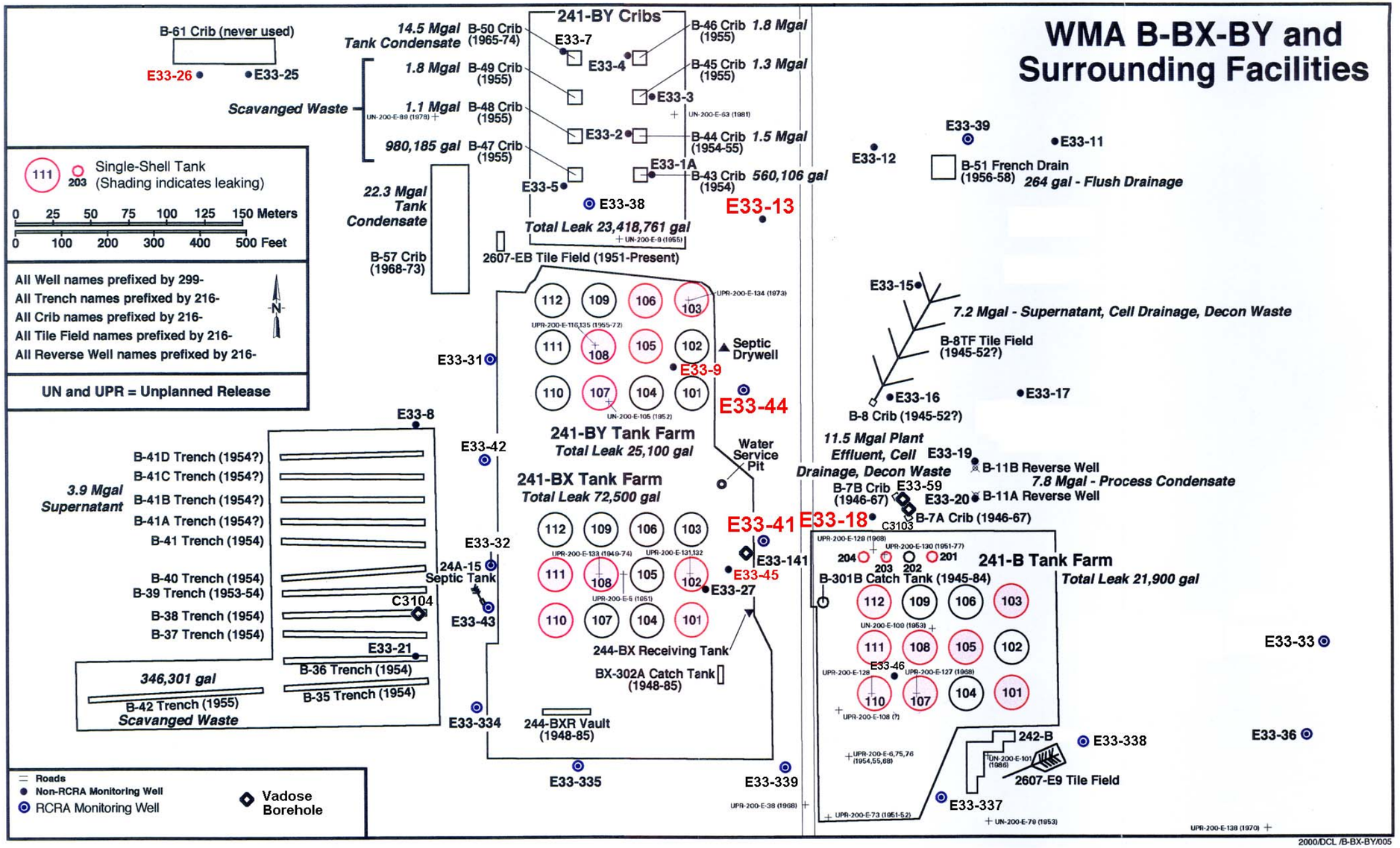
Executive Summary

The U.S. Department of Energy Richland Office (DOE-RL) tasked the DOE Grand Junction Office (DOE-GJO) to conduct a baseline characterization of the gamma-ray-emitting radionuclides distributed in vadose zone sediments in the vicinity of waste sites in the Central Plateau (200 East and West Areas) of the Hanford Site. The Spectral Gamma Logging System (SGLS) was used to collect data in existing boreholes and monitoring wells, as well as, perform geophysical logging of new boreholes and wells drilled as part of ongoing site investigation projects. This system uses a high-purity germanium (HPGe) detector to acquire high-resolution, gamma-energy spectra for the detection, identification, and quantification of gamma-emitting radionuclides. This baseline supports the 200 Areas Remedial Investigation/Feasibility Study (RI/FS) (DOE 1999a) by collecting data at individual waste sites that are used to verify the applicability of the representative waste site conceptual model, to confirm that remedial action decisions are appropriate, and to provide data needed to design the remedy. This work is an extension of a baseline characterization conducted within tank farms between 1995 and 2000.

This report integrates SGLS results obtained from 284 boreholes located in the waste sites surrounding the B-BX-BY Waste Management Area (WMA) and within the B-BX-BY Tank Farms (Figure ES-1). This SGLS dataset consists of more than 70,000 individual measurements. The purpose of this report is to integrate data from prior baseline characterization reports with recent characterization activities in the WMA and adjacent waste sites. SGLS data collected between 1995 and 2000 for the tank farms baseline characterization are incorporated with data collected between 2001 and 2003 for the 200 Areas baseline characterization, recently drilled RCRA groundwater wells, tank farm investigations, and RI/FS waste site characterizations to evaluate the relationships of waste sites, contamination, and stratigraphy. When data are evaluated as a whole, sources of contamination are clearly delineated and the relative impact of waste disposal practices can be evaluated. Borehole log data are presented in waste site summary reports for the 216-B-35 to -42 Trenches (DOE 2002a), 216-B-8 Crib and adjacent sites (DOE 2002b), and the 216-B-43 to -50, -57, and -61 Cribs and adjacent waste sites (DOE 2003a). Tank farm data are presented in the B, BX, and BY Tank Farm Reports and addenda (DOE 1997a, 1998a, 2000a, 2000b, 2000c, and 2000d).

Antimony-125 (^{125}Sb), cesium-137 (^{137}Cs), cobalt-60 (^{60}Co), europium-152 (^{152}Eu), europium-154 (^{154}Eu), uranium-235 (^{235}U), and uranium-238 (^{238}U) were detected while logging in this study area. ^{125}Sb was detected near tanks BX-101, BX-102 (BX Tank Farm), and BY-103 (BY Tank Farm), as well as, near the 216-B-41 Trench and the BY Cribs. Maximum concentrations do not exceed 10 picocuries per gram (pCi/g). ^{137}Cs was detected in the vadose zone at all of the waste sites and tank farms in the study area. Maximum concentrations exceed 20 million pCi/g near tanks BX-102 and BX-110. Concentrations of ^{137}Cs greater than 1 million pCi/g are limited to elevations above 525 feet (ft) mean sea level (msl) or above log depths of approximately 135 ft underneath the tank farms and the BY Cribs. Measured^{137}Cs concentrations are less than 200,000 pCi/g underneath the remaining waste sites in the study area. Other than at the BY Cribs and BY Tank Farm, ^{60}Co was generally detected below the base of a waste site or tank and confined to the upper vadose zone. Below the BY Cribs, ^{60}Co was encountered from the base of the cribs to groundwater. Isolated occurrences of ^{60}Co were encountered in the intervals between elevations of 477 to 462 ft (177 to 192 ft log depth) and 445 to 443 ft (209 to 211 ft log depth) in borehole 299-E33-9 and at elevations of 475 to 470 ft (157 to 162 ft log depth) in borehole 299-E33-13. ^{154}Eu was encountered in all three of the tank farms, the 216-B-7A Crib, and the BY Cribs. ^{154}Eu was detected in 21 boreholes at



Modified from Narbutovskih (2000)

Figure ES-1. Map of the B-BX-BY Waste Management Area and Surrounding Facilities and Significant Boreholes

elevations between 661 and 546 ft (~0 to ~105 ft log depth). The highest measured concentration was127 pCi/g near tank BX-101. The distribution of ^{152}Eu in the vadose zone is similar to that of ^{154}Eu. The ^{152}Eu contamination generally occurs at much lower concentrations than the ^{154}Eu within the vadose zone sediments. SGLS measurements detected processed uranium (^{235}U and ^{238}U) in 17 of 284 boreholes. ^{235}U concentrations are generally an order of magnitude less than ^{238}U concentrations. The most extensive area of $^{235/238}$U contamination is located northeast of tank BX-102. This area contains 13 of the 17 boreholes where processed uranium was detected. ^{238}U concentrations reached 1,000 pCi/g east of tank BX-102. Processed uranium was detected near tanks BX-106 and BY-111 in nearby boreholes. Borehole 299-E33-18, located approximately 80 ft west of the 216-B-7A&B Cribs, exhibited ^{238}U contamination at elevations between 421 and 401 ft (234 and 254 ft log depth) at concentrations exceeding 500 pCi/g. Near the 216-B-7B Crib at borehole 299-E33-59, $^{235/238}$U was detected between elevations of 612 and 600 ft (42 and 54 ft log depth) at concentrations of 32 pCi/g for ^{238}U. Soil samples (DOE 1993b and DOE 2003b) collected in the BY Cribs, 216-B-38 Trench (borehole C3104), 216-B-57 Crib, and 216-B-7A Crib (borehole C3103) indicate that uranium above background levels (0.3 to 1.5 pCi/g) is present only in the upper vadose zone (above an elevation of 600 ft or ~ 60 ft below the ground surface). These elevated levels of ^{238}U (~100 pCi/g) occur in the zones of very high gamma flux due to concentrations of ^{137}Cs in excess of 1,000 pCi/g. Because of the very high gamma flux caused by ^{137}Cs, the minimum detection level (MDL) for uranium and other isotopes is increased such that concentrations cannot be quantified by the SGLS in these intervals. Below the high-activity zones, ^{238}U above background concentrations was not detected by spectral gamma logging in the vadose zone or reported in the available soil samples (DOE 2003b) except in boreholes near tank BX-102.

Previous investigators have established the following:

- A spill of 22.5 tons of uranium occurred at tank BX-102 (General Electric 1951).
- Processed uranium in the vadose zone detected at well 299-E33-41 is considered part of the processed uranium vadose zone plume extending out of the BX Tank Farm (Narbutoskih 1998; Pruess and Yabusaki in Knepp 2002).
- Log data acquired in two groundwater wells (299-E33-18 and -41) located northeast of tank BX-102 and outside the BX Tank Farm showed an influx of uranium contamination between 1991 and 1997 (Price 1998, PNNL 1999, and DOE 2002b). In well 299-E33-41, ^{238}U increased from 200 to 1,000 pCi/g between 1991and 1997 in a zone between elevations of 435 and 415 ft (220 and 240 ft log depth). Processed uranium was detected just above groundwater in the interval between elevations of 421 and 401 ft (234 and 254 ft log depth) with a maximum concentration of 600 pCi/g in groundwater well 299-E33-18.
- Between 1994 and 2002, an extensive southeast-northwest-trending uranium groundwater plume developed in the vicinity of the B-BX-BY WMA. In 1994, uranium concentrations above the MCL were reported by PNNL (1995) in only two wells (299-E33-13 and -18). Groundwater conditions in 2002, as reported by PNNL (2003), indicate that the uranium groundwater plume has increased to 2,500 ft in length. Groundwater elevation is at approximately 401 ft in this area (~255 ft log depth).

The significant conclusions of the evaluation of SGLS data are as follows:

- The spill of uranium at tank BX-102 is the apparent source of the uranium contamination in the groundwater. The uranium contamination from tank BX-102 has traveled to the northeast through the vadose zone. Based on relatively dense well control, the uranium can be tracked across the BX Tank Farm boundary as far as borehole 299-E33-41 and to within 12 ft above groundwater. Uranium migration is following the northeast stratigraphic dip in this area. Processed uranium has reached groundwater well 299-E33-18 at an elevation of 401 ft (approximately 254 ft log depth and just above groundwater) and a lateral distance of 400 ft to the northeast from its presumed source at the tank BX-102 spill. Evaluation of log data indicates the contamination reached this location between 1991 and 1997 (Price 1998, PNNL 1999, and DOE 2002b). Once uranium reaches the perched water within the Cold Creek Interval, it can be transported laterally at an increased rate over relatively large distances. Groundwater monitoring data acquired by Pacific Northwest National Laboratory (PNNL 2002a) indicate that uranium (above the maximum contaminant level [MCL]) was first detected in groundwater in January 1994 northeast of tank BX-102 and has since increased in concentration.

- The uranium groundwater plume appears to originate northeast of well 299-E33-41 and near wells 299-E33-18 and -44. Between 1994 and 2002, uranium concentrations in groundwater have increased, and the uranium groundwater plume has expanded to the northwest. Uranium in groundwater has moved northwest, reached groundwater underneath the 216-B-61 Crib, and extended beyond the 200 East Area boundary. SGLS logging in the study area has not identified other tanks and waste sites as potential sources of uranium contamination in groundwater. The spill at tank BX-102 is the only credible source of uranium in groundwater.

The recently completed investigations of the waste sites (DOE 2003b) and the B-BX-BY WMA (Knepp 2002) arrived at conflicting conclusions with respect to the development of the current uranium groundwater plume. The remedial investigation report (DOE 2003b) for the waste sites adjacent to the WMA suggested that these waste sites are not the source of the uranium observed in the groundwater; however, the WMA field investigation report (Knepp 2002) implied that the nearby waste sites are the source of the current uranium groundwater contamination. The major conclusion of the B-BX-BY Field Investigation Report (Knepp 2002) was: "*The future impacts from wastes currently in the vadose zone that resulted from past releases from the B, BX, or BY Tank Farms are not expected to exceed drinking water standards as long as high volume liquid discharges to the vadose zone are eliminated.*"

The differences in the extent and impact of the tank BX-102 uranium vadose zone plume as evaluated by Knepp (2002) and this report occur because this report includes SGLS results from both inside and outside the B-BX-BY WMA boundary, and Knepp (2002) did not include geophysical data from boreholes 299-E33-45 and 299-E33-41. By excluding the log results from 299-E33-45 and 299-E33-41, both the vertical and lateral extents of the uranium contamination as evaluated by Knepp (2002) are underestimated, as are the projected environmental impacts.

Additional major conclusions of the evaluation of SGLS data are as follows:

- Based on the SGLS logging, all of the BY Cribs appear to have received similar waste streams, and characterization results collected at the 216-B-46 Crib are applicable under the analogous site concept (DOE 1999a) to all of the BY Cribs. Currently, the 216-B-50 Crib is

grouped with the 200-PW-5 Operable Unit; however, SGLS results for this area are consistent with results for nearby cribs that are in the 200-TW-1 Operable Unit.

- ^{60}Co and ^{137}Cs were identified throughout the deep vadose zone in the Cold Creek Unit. This contamination was detected just above the current groundwater level and within the groundwater. However, it is only observed in RCRA non-compliant groundwater wells that were drilled before the mid-1970s. Boreholes drilled since the late 1970s do not exhibit this contamination. Evidence of ^{137}Cs is probably related to perched water that resulted from disposal of significant volumes of fluids to waste sites. The source of the majority of the historical ^{137}Cs contamination is probably the BY Cribs. Other waste sites that may also have contributed ^{137}Cs to the deep vadose zone are the 216-B-36 and -37 Trenches and the 216-B-8 Crib. Boreholes located near tanks BX-102, BX-107, and BX-110 in the BX Tank Farm and tank B-110 in the B Tank Farm exhibit high levels (greater than 10,000 pCi/g) of ^{137}Cs and may also be in the immediate vicinity of potential sources of the contamination. The ^{60}Co is probably the result of historical groundwater contamination that originated from the BY Cribs. It is possible that the BY Tank Farm may also be a source of ^{137}Cs and ^{60}Co contamination in the deep vadose zone, but the nature and extent of contamination are not known because the majority of boreholes in the BY Tank Farms are only 100 ft in depth or do not penetrate below an elevation of approximately 550 ft. The low levels (less than 10 pCi/g) of ^{137}Cs and ^{60}Co near the current groundwater level appear to be remnants of contamination adsorbed to rust or scale in the casing when water levels were higher or due to perched water that mobilized the contamination.

- The most extensive ^{137}Cs vadose plumes in terms of volume do not appear to be associated with the tank farms; however, the deep vadose zone has not been investigated because the tank farm boreholes were generally drilled to less than 150 ft in depth or do not penetrate below an elevation of approximately 500 ft. The largest ^{137}Cs vadose zone plume occurs underneath the BX Trenches. Other relatively large ^{137}Cs vadose zone plumes lie below the BY Cribs and the 216-B-8 Crib and Tile Field.

- A widespread low-level ^{60}Co plume (less than 10 pCi/g) extends from the base of the BY Cribs to groundwater. Comparison of log data with soil samples (DOE 1993b) in two deep boreholes in the BY Cribs suggests that technetium-99 (^{99}Tc) may co-exist with the ^{60}Co or has followed similar migration pathways through the vadose zone (DOE 2003a). Contamination from the BY Cribs has also spread laterally in the vadose zone. The full extent of ^{60}Co contamination underneath the BY Tank Farm is unknown.

- The possible sources of the ^{60}Co detected in groundwater well 299-E33-13 at elevation of 475 ft (log depth 157 ft) is unknown. The closest potential sources are tank BY-103, located 200 ft to the southwest, or the BY Cribs, located 270 ft to the northwest. The stratigraphic dip of the Hanford is to the northeast, which suggests that the leak from tank BY-103 is the most likely source.

- SGLS log results are not consistent with the Hanford Soil Inventory Model (Simpson et al. 2001) estimates for uranium and ^{60}Co releases to the vadose zone. The Hanford Soil Inventory Model (Simpson et al. 2001) did not estimate releases in the BY Tank Farm, the 215-B-57 Crib, and the 216-B-50 Crib. Substantial inventories of uranium are predicted by the model for the BX Trenches, 216-B-7A & -7B Cribs, the BY Cribs, and the 216-B-8 Crib

and Tile Field. The SGLS detected a minor amount of processed uranium only near the 216-B-7B Crib. These results are more consistent with the GE (1951), Haney and Honstead (1958), and Fecht et al. (1977) inventory estimates. Simpson et al. (2001) compared calculated soil data inventory and soil inventory model estimates for the BY Cribs. The results of this comparison were that the soil inventory model derived estimates were too high, usually about an order of magnitude (Simpson et al. 2001). SGLS logging indicates that the majority of the ^{60}Co contamination in the vadose zone is associated with the BY Cribs, and, to a lesser extent, the BY Tank Farm. Simpson et al. (2001) indicated that the greatest releases of ^{60}Co occurred at B Tank Farm, where a cumulative 2.7 Curies (Ci) of ^{60}Co were lost to the vadose zone, and that only 0.0014 Ci of ^{60}Co were discharged to the vadose zone at the BY Cribs. The current estimate of ^{60}Co releases for the BY Cribs appears to be too low.

- A comparison of the profiles of historical gross gamma logs and current SGLS logs, as well as, a more direct comparison of more recent RLS spectral logs with the SGLS, suggest that ^{137}Cs contamination tends not to migrate over time, while ^{60}Co and ^{238}U are more mobile. A program established by DOE-ORP in July 2001 to monitor gamma activity in tank farm boreholes generally suggests a lack of contaminant movement.

Recommendations include the installation of additional boreholes to better define areas of contamination, further assessment of tank leaks in the area, and revision of the Hanford Soil Inventory Model (Simpson et al. 2001). Future monitoring efforts should be extended to boreholes in and near waste sites to assess the stability of vadose zone contamination throughout the B-BX-BY WMA and adjacent waste sites. These additional data can be used to refine the System Assessment Capability to more accurately predict contaminant migration and risk.

1.0 Introduction

The Hanford 200 Areas Spectral Gamma Baseline Characterization Project team deploys borehole geophysical logging equipment to measure naturally occurring and anthropogenic radionuclides in the subsurface in the vicinity of 200 Area waste sites. The purpose of this report is to update the conclusions of prior baseline characterization reports and incorporate results of recent characterization activities. The following sections provide brief discussions of background, project purpose and scope, and project objectives.

1.1 Background

The U.S. Department of Energy (DOE) Hanford Site encompasses approximately 1,450 km^2 (560 mi^2) in the Columbia Basin of south central Washington State. Beginning in World War II, the Hanford Site was involved in production of plutonium to support the national nuclear weapons program. The Hanford Site is subdivided into a number of operational regions identified as the 100, 200, 300, and 1100 Areas (Figure 1). In 1989, the U.S. Environmental Protection Agency (EPA) placed these areas on the National Priorities List (NPL) pursuant to the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). The 200 Areas, located on a plateau near the center of the Hanford Site, consist of the 200 West Area and 200 East Area, which include waste management facilities and inactive irradiated-fuel reprocessing facilities, and the 200 North Area, which was formerly used for interim storage and staging of irradiated fuel.

1.2 Purpose and Scope of Project

The goal of the DOE Grand Junction Office (DOE-GJO) Hanford 200 Areas Spectral Gamma Baseline Characterization Project is to collect data from existing boreholes and determine the present nature and extent of contamination associated with gamma-ray-emitting radionuclides distributed in the subsurface in the vicinity of 200 Area waste sites. This project is an extension of the Tank Farms Vadose Zone Characterization Project that was completed in 2000. The investigation includes liquid waste disposal sites and associated structures such as pipelines that were used for discharge of radioactive liquids from processing facilities to the ground (e.g., ponds, cribs, and ditches), burial grounds, the peripheral regions of the single-shell waste storage tank farms where leakage of high-level radioactive waste constituents from specific tanks may have migrated, and unplanned releases. Most of the liquid waste sites and all of the burial grounds and unplanned release sites have been assigned to the Environmental Restoration (ER) Program. A small percentage of the soil waste sites and the peripheral regions of the tank farms have been assigned to the DOE Office of River Protection (DOE-ORP).

The purpose of the Hanford 200 Areas Spectral Gamma Baseline Characterization Project is to present spectral gamma data collected from existing boreholes in and adjacent to waste sites in the Hanford 200 Areas. This baseline supports the 200 Areas Remedial Investigation/Feasibility Study (RI/FS) by collecting data at individual waste sites that are used to verify the applicability of the representative waste site conceptual model, to confirm that remedial action decisions are appropriate, and to provide data needed to design the remedy (DOE 1999a). High-resolution gamma-energy spectra are collected in existing boreholes using consistent and defensible methodology. This work extends the existing baseline data set developed for the Hanford single-shell tank farms into the surrounding areas. The baseline data are evaluated to determine the source(s) of the contamination,

to develop a dataset that can be used to assess future changes, and to correlate the geophysical signatures of known and presumed geologic features that may affect radionuclide migration within the vadose zone. This information is needed to manage the sites and to make informed decisions about subsequent environmental activities.

The Spectral Gamma Logging System (SGLS) is used to acquire gamma-ray energy spectra from boreholes and wells related to the 200 Area waste sites. Intervals of high gamma-ray intensity are logged with the High Rate Logging System (HRLS).

Gamma spectra from each borehole are analyzed to determine concentrations of naturally occurring radionuclides potassium-40 (^{40}K), thorium-232 (^{232}Th), uranium-238 (^{238}U), and associated decay progeny, as well as, man-made gamma-emitting radionuclides such as cesium-137 (^{137}Cs), cobalt-60 (^{60}Co), and europium-152/154 ($^{152/154}$Eu). Variations in naturally occurring radionuclides are useful in stratigraphic correlation.

This project is limited in scope to passive spectral gamma-ray logging. As a result, only radionuclides that decay with the emission of gamma-ray photons can be detected and quantified. In some cases, strontium-90 (^{90}Sr) can be detected. Only existing boreholes/wells and boreholes recently drilled for other projects are logged. No new borehole drilling is specified or planned as a part of this project, although recommendations for additional boreholes may be provided when appropriate. Additional details regarding the scope and general approach to this characterization program are included in the baseline characterization plan (DOE 2003c) and project management plan (DOE 2003d).

Specific activities under this project include preparation and maintenance of a database of existing boreholes and geophysical log data, logging existing boreholes with the SGLS and HRLS, analyses and plotting of log data, and preparation of reports. Because the waste sites are the subjects of site characterization efforts in RI/FS work plans, well logging is performed in existing and new boreholes to support these activities, and data are provided for incorporation into the Remedial Investigation Reports.

1.3 Project Objectives

Specific project objectives are:

- To use passive spectral gamma logging to identify the activities of man-made radionuclide contaminants and to estimate current subsurface radionuclide contamination in the vicinity of 200 Area waste sites. Many areas of the subsurface have been contaminated by the disposal of liquid waste to the ground, and, in some cases, by surface spills.

- To identify probable sources of contamination by measuring the radionuclide contaminant activity in multiple boreholes and correlating data between those boreholes, and to link detected contamination with probable sources.

- To provide a baseline dataset to help assess ongoing migration of the radionuclides through the vadose zone, and to provide data for the validation and/or determination of initial or boundary conditions of contaminant transport models.

- To generate data that can be used for stratigraphic correlations in 200 Area waste sites. Migration of radionuclides through the vadose zone is affected by differences in vadose zone composition, porosity, density, and water content. Accurate stratigraphic characterization helps in identifying target-monitoring horizons and in delineating controlling factors in subsurface flow. Lithologic characterization data include vertical profiles of naturally occurring ^{40}K, ^{238}U, and ^{232}Th.

Although the primary focus of this project is interpretation and evaluation of spectral gamma logs, part of this project involves assessment of existing data, such as historical gross gamma data, spectral gamma and neutron logs, drilling logs, groundwater monitoring information, geology and hydrogeology information, construction details, and operational information. This information is compiled and evaluated with the spectral gamma data to understand its significance in relation to the nature and extent of vadose zone contamination. The background and historical information help to identify potential sources of contamination, the date of contamination, rate of contaminant migration (if it occurs), and to explain the nature of the contamination identified by the new spectral gamma log data.

2.0 Spectral Gamma-Ray Logging Methods

The following sections discuss field and technical methods used by the Hanford 200 Areas Spectral Gamma Baseline Characterization Project that have been specifically developed for high-resolution borehole measurements with a sensitivity and accuracy comparable to laboratory equipment.

2.1 Field Methods

Existing boreholes are logged by the SGLS, which uses cryogenically cooled HPGe detectors with an intrinsic efficiency of approximately 35 or 70 percent. A HRLS is used in zones of high gamma activity, where the SGLS detector can become "saturated" and no usable spectra can be acquired. Both detector systems are operated on the same logging vehicle. Each combination of sonde and logging vehicle represents a unique logging system. Two logging vehicles, three SGLS sondes, and one HRLS sonde are available.

SGLS and HRLS log data are collected in accordance with a logging procedure (DOE 2001). Gamma energy spectra are collected in "move-stop-acquire" mode where the sonde is held stationary for measurement and then moved a specified depth increment to the next measurement point. The typical depth increment is 1.0 feet (ft). System gain is adjusted as necessary to maintain a consistent channel relationship for a marker peak (typically the ^{40}K peak at 1461 kilo-electron volts [keV]). Measurement times are selected to detect prominent gamma peaks associated with natural radionuclides (^{40}K, ^{238}U, and ^{232}Th). Depending on casing thickness, typical count times are 100 or 200 seconds (sec) for the SGLS and 300 sec for the HRLS. This results in logging speeds of feet per hour instead of the feet per minute rates common in the petroleum and mineral industries. Verification spectra are collected at the beginning and end of each logging day to monitor system performance, and repeat sections are logged to demonstrate repeatability and consistency.

2.2 Technical Methods

Evaluation of gamma energy spectra provides identification and quantification of naturally occurring and man-made radionuclides based on characteristic energy emissions associated with their decay. Only gamma rays of sufficient energy to penetrate the steel borehole casing and sonde housing can be detected by the SGLS or HRLS. Radionuclides that emit one or more gamma rays at energies between about 150 and 2,800 keV are detectable with the SGLS. The minimum detectable concentration is dependent upon detector efficiency at the appropriate energy, background activity, and the yield (gamma rays emitted, on average, per decay). Factors such as casing, water, shielding, and the presence of other radionuclides also have an effect. Because waste disposal to the soil column has been discontinued, radionuclides with half lives of less than 1 year have not been detected on the spectral gamma logs and are presumed to have decayed to insignificant levels. Tables 2-1 and 2-2 summarize naturally occurring and man-made radionuclides that can be detected with the SGLS. The terms "primary gamma ray" and "secondary gamma ray" are used to differentiate between the more prominent gamma energy peaks and other, less prominent peaks that may be useful for confirmation. The values indicated in bold are those generally used to calculate concentrations.

Table 2-1. Naturally Occurring Gamma-Emitting Radionuclides

	Primary Gamma Rays			Secondary Gamma Rays		
Radionuclide	**Daughter**	**E (keV)**	**Y (%)**	**Daughter**	**E (keV)**	**Y (%)**
^{40}K		**1460.83**	**10.67**			
^{232}Th	^{212}Pb	238.63	43.30	^{228}Ac	911.21	26.60
	^{208}Tl	**2614.53**	**35.64**	^{228}Ac	968.97	16.17
	^{208}Tl	583.19	30.36	^{228}Ac	338.32	11.25
				^{208}Tl	510.77	8.06
^{238}U[1]	^{214}Bi	**609.31**	**44.79**	^{214}Pb	295.21	18.50
	^{214}Pb	351.92	35.80	^{214}Bi	1120.29	14.80
	^{214}Bi	**1764.49**	**15.36**	^{214}Pb	241.98	7.50
				^{214}Bi	1238.11	5.86
				^{214}Bi	2204.21	4.86
				^{214}Bi	2447.86	1.50

[1] Attainment of secular equilibrium between ^{238}U and $^{214}Bi/^{214}Pb$ requires long time periods on the order of a million years. Activities of both ^{214}Bi and ^{214}Pb are commonly assumed to be equal to the activity of naturally occurring ^{238}U. However, these radionuclides are short-term daughter products of ^{222}Rn, and accumulations of radon gas inside the casing may temporarily elevate the decay activities of $^{214}Bi/^{214}Pb$ relative to the decay activity of ^{238}U.

Table 2-2. Man-Made Radionuclides

Radionuclide	Half Life (Years)	Primary Gamma Rays		Secondary Gamma Rays	
		E (keV)	Y (%)	E (keV)	Y (%)
^{60}Co	5.2714	**1332.50** **1173.24**	**99.98** **99.90**		
^{106}Ru	1.0238	511.86	20.40	621.93	9.93
^{125}Sb	2.7582	**427.88**	**29.60**	600.60 635.95 463.37	17.86 11.31 10.49
^{126}Sn	1.E+5	**414.50**	**86.00**	666.10 694.80	86.00 82.56
^{134}Cs	2.062	604.70	97.56	795.85	85.44
^{137}Cs	30.07	**661.66**	**85.10**		
^{152}Eu	13.542	**1408.01**	**20.87**	121.78 344.28 964.13 1112.12 778.90	28.42 26.58 14.34 13.54 12.96
^{154}Eu	8.593	**1274.44**	**35.19**	123.07 723.31 1004.73 873.19	40.79 20.22 18.01 12.27
^{155}Eu	4.7611	105.31	21.15		
^{235}U	7.038E+08	**185.72**	**57.20**	205.31	5.01
^{234m}Pa (^{238}U[1])	4.47E+09	**1001.03**	**0.84**	811.00 766.36	0.51 0.29
^{237}Np	2.14E+06	312.17	38.60		
^{238}Pu	87.7	99.853	0.0074	43.498	0.04
^{239}Pu	24110	129.30 **375.05** 413.71	0.0063 **0.0016** 0.0015		
^{240}Pu	6563	104.234	0.007	45.244 160.308	0.045 0.0004
^{241}Pu	14.35	148.567	0.0002	103.68	0.0001
^{241}Am	432.2	59.54[2] 662.40[3]	35.90 0.0004	102.98 335.37 368.05 722.01	0.02 0.0005 0.0002 0.0002

[1] ^{234m}Pa is a short-term daughter of ^{238}U. Secular equilibrium is achieved relatively quickly. Because of the relatively low gamma yield, this peak is not observed when only background levels of naturally occurring ^{238}U are present. Hence, the presence of gamma peaks associated with ^{234m}Pa without corresponding peaks associated with ^{214}Pb and ^{214}Bi indicates the presence of chemically processed uranium.

[2] The 59.54-keV gamma ray may not be detectable in thick casing.

[3] Although the yield for this gamma ray is very poor, it is much more penetrating than the 59.54-keV line and may be detected. This can lead to a situation in which the presence of a gamma line at 662 keV is interpreted as ^{137}Cs, when it is in fact ^{241}Am. Identification of ^{241}Am can be confirmed by the presence of gamma activity at 722.01 keV and 335.37 keV.

Other radionuclides of interest, such as tritium (^{3}H), ^{90}Sr, and technetium-99 (^{99}Tc), are "pure" beta emitters and do not emit any gamma rays that can be detected with the SGLS. However, computer modeling investigations and experience with data interpretation have shown that in the absence of

other contaminants, the presence of ^{90}Sr at concentrations greater than about 1,000 pCi/g can be inferred from the *bremsstrahlung* generated from interaction of the high-energy beta emissions from ^{90}Sr with the steel casing (DOE 2002c).

Field gamma spectra are processed and analyzed in accordance with a data analysis manual (DOE 2003e). Conventional gamma spectra analysis software is used to detect gamma energy peaks, identify the source radionuclide, and determine the net count rate, counting error, and minimum detectable activity. From the net count rate ($P_{n,}$ cps) for a specific energy peak, the apparent concentration of the source radionuclide ($C_{a,}$ pCi/g) is determined by:

$$C_a = \frac{27.027}{Y} \times I(E) \times DTC \times K_c \times K_w \times K_s \times P_n ,$$

where Y is the radionuclide yield, I(E) is the logging system calibration function, DTC is the dead time correction, and K_c, K_w, and K_s are energy-dependent correction factors for casing, water, and shielding. The calibration function, I(E), is unique for each combination of sonde and logging vehicle. Values of the calibration function are updated annually and documented in calibration certificates and a calibration report (Koizumi 2002). Concentration error and minimum detectable concentration are calculated using similar equations. The reported concentration error is based on only the estimated counting error. No effort is made to include the effects of errors in the calibration function or correction factors. These errors are discussed in the calibration report (Koizumi 2002). The term "apparent concentration" is used because concentrations are calculated from log data under the assumption that the in situ source distributions are not significantly different from the source distributions in the calibration standards. However, the calibration standards have gamma source distributions that are homogeneous and effectively infinite in spatial extent (with respect to radiation transport), whereas the source distributions in the subsurface may be inhomogeneous and more limited in spatial extent.

The minimum detection level (MDL) of a radionuclide represents the lowest concentration at which the positive identification of a gamma-ray peak for that radionuclide is statistically defensible. A description of the MDL calculation is included in the data analysis manual (DOE 2003e).

For a counting time of 100 sec, the MDL for ^{137}Cs is typically about 0.2 pCi/g. The MDL differs slightly for each spectrum depending upon count time, background activity and concentrations of other radionuclides at the data point, as well as casing thickness. In regions of higher concentrations of man-made radionuclides, the Compton background continuum becomes elevated, increasing the MDL value.

The MDL for ^{60}Co is about 0.15 pCi/g; the MDL for ^{154}Eu is approximately 0.2 pCi/g; and the MDLs for ^{235}U and ^{238}U are approximately 1 and 10 pCi/g, respectively. These values are typical for a 100-sec counting time in the absence of other gamma-emitting radionuclides.

Natural and man-made radionuclide concentrations, total gamma count rate, and dead time are plotted as a function of depth. These plots are included in a Log Data Report for each borehole that also summarizes borehole construction details, logging conditions, analysis notes, and log plot notes, as well as a brief discussion of results and interpretations. When appropriate, comparison plots with other available logs are also included.

Log data and geological information from surrounding boreholes are assembled and correlated in an effort to identify contaminated zones and potential sources of contamination. Historical gross gamma, spectral gamma, and neutron log data are incorporated where available. Three-dimensional geostatistical visualization software is used to interpolate data between boreholes.

A Waste Site Summary Report (WSSR) documents the results of the correlation and evaluation process for each group of waste sites. Waste site groups have been defined in terms of physical proximity and common configuration or operational history. Each WSSR provides a review of background information that includes a description and operational history of the waste sites, a summary of geologic and hydrogeologic conditions, a review of previous investigations, and any existing data such as gross gamma or spectral logs, geologic logs, soil samples, and groundwater analytical data. An assessment and interpretation of the spectral gamma-ray log information are also provided, along with conclusions and recommendations on future data needs or corrective action, where appropriate.

3.0 Background and Physical Setting of the B-BX-BY WMA and Adjacent Waste Sites

Figure 2 is a map of the B-BX-BY Waste Management Area and vicinity that shows the location of the boreholes, tank farms and waste sites. Figures B-1 and B-5 (Appendix B) are more detailed maps of waste sites northeast of the B-BX-BY WMA and the BY Cribs, respectively. The major waste sites within the area that have existing boreholes available for evaluation are the 216-B-35, 216-B-36, 216-B-37, 216-B-38, and 216-B-41 Trenches, BY Cribs (216-B-43 to -50), 216-B-57 Crib, 216-B-7A&B Cribs, 216-B-8 Crib and Tile Field, 216-B-11A&B French Drains, B Tank Farm, BX Tank Farm, and BY Tank Farm. Other waste sites that do not have boreholes located nearby are the 216-B-39, 216-B-40, and 216-B-42 Trenches, 216-B-51 French Drain, 216-BY-201 Settling Tank, 241-B-151, -152, -153, and -252 Diversion Boxes, 244-BX-DCRT (Double Contained Receiving Tank), and 241-B-301B Catch Tank. The 216-B-61 Crib has two nearby groundwater wells; however, this crib was not used as a waste disposal facility. The study area is bounded in the north by the 200 East boundary, in the west by the Low Level Waste Management Area (LLWMA) 1, and in the southwest by the 216-E-2, 216-E-2A, 216-E-5, 216-E-5A, and 216-E-9 Burial Grounds. The southeast and east boundaries were selected to include deep boreholes in the area that are not generally associated with specific waste sites but are useful to bound the extent of contamination.

The information in the following sections was obtained from a variety of sources, including Waste Information Data System (WIDS), System Assessment Capability (SAC), Simpson et al. (2001), *B Plant Source Aggregate Area Management Study Report* (DOE 1993a), Brodeur et al. (1993), Wood et al. (2000a), Knepp (2002), waste site reports for the 200 Areas Vadose Zone Characterization Project (DOE 2002a, 2002b, 2003a), the B, BX, and BY Tank Farm Reports and their addenda (DOE 1997a, 1998a, 2000a, 2000b, 2000c, and 2000d) and a recent remedial investigation report (DOE 2003b).

3.1 Background of the 200 Areas

Established in 1943, the Hanford Site was originally designed, built, and operated to produce plutonium for nuclear weapons. Uranium metal billets were received in the 300 Area and fabricated into jacketed fuel rods. The fuel rods were loaded into graphite-moderated reactors in the 100 Areas. With the exception of 100-N, which also provided steam to the Hanford Generating Project, these reactors were operated for the sole purpose of producing ^{239}Pu from neutron activation of ^{238}U. The fuel rods were then transported to the 200 Areas, where plutonium and uranium were separated from the residual activation and fission products using a variety of liquid chemical separation processes. The 600 Area includes portions of the Hanford Site not included in the 100, 200, or 300 Areas and served primarily as transportation corridors and buffer zones between the fabrication, irradiation, and chemical processing areas (DOE 1998b).

Chemical separations process facilities were sited in both the 200 East and 200 West Areas. The 200 North Area temporarily stored irradiated fuel rods, allowing short-lived fission products to decay before the fuel was shipped to separations plants. With the startup of the separation plants, high-level wastes containing the bulk of the fission products were discharged to large underground steel tanks, and large quantities of liquid wastes (primarily water) containing minor concentrations of radionuclides and chemicals were discharged to the soil column and percolated into the vadose zone. Depending on contaminant concentrations and a consequent need for isolation, liquid wastes were discharged either to surface ponds and ditches or to underground cribs, trenches, and French drains. Liquid wastes were divided into high (more than 100 microcuries [μCi] of beta emitters per milliliter), intermediate (more than 5×10^{-5} μCi and less than 100 μCi of beta emitters per milliliter), and low-level (less than 5×10^{-5} μCi of beta emitters per milliliter) categories (Routson 1973). The high-level wastes were sent to the tanks for storage. The intermediate level wastes were disposed to cribs. "*Cribs are underground structures from which the solution percolates through the sediment (soil) to the groundwater*" (Routson 1973). "*Limited amounts of special intermediate wastes were disposed to the ground in trenches on a specific retention basis*" (Routson 1973). These liquid disposal sites were located in the 200 Areas near the processing plants and in the nearby 600 Areas (DOE 1998b). Before 1950, injection wells and/or reverse wells were used to dispose of process waste directly to groundwater.

3.2 Geologic Conditions

This section summarizes the geologic setting of the Hanford Site, specifically the northwest quadrant of the 200 East Area. Figure 3 shows the general stratigraphy for the B-BX-BY WMA and vicinity. Lithologic information, used to develop stratigraphy, is obtained from field analysis of sediment samples retrieved during borehole drilling operations and from nearby outcrops. When available, gross gamma-ray logs have been used to support the geologic interpretation. Most of the boreholes were drilled with a cable tool drill rig, and the samples were obtained from bailings, core barrels, or as retained cuttings, generally from 5-ft intervals. Lindsey and Law (1993), Lindsey et al. (1994), and Wood et al. (2000a) presented detailed descriptions and interpretations of the geologic formations near and within the B-BX-BY WMA.

3.2.1 Stratigraphy

Overlying the basalt flows of the Columbia River Basalt Group are the Ringold Formation, the Cold Creek Interval (Plio-Pleistocene unit), the informal Hanford formation, and Holocene-Age deposits.

Rockwell (1979), Reidel et al. (1992), Delaney et al. (1991), Lindsey (1991), Lindsey et al. (1994), and DOE (2002d) have presented extensive descriptions and discussions of these formations. DOE (2002d) formalized the stratigraphic nomenclature for post-Ringold sediments at the Hanford Site, and this nomenclature is used in this report.

3.2.1.1 Columbia River Basalt Group

The Columbia River Basalt Group consists of tholeiitic flood-basalt flows that erupted between 17 and 6 million years ago and cover approximately 164,000 km^2 of eastern Washington, Oregon, and western Idaho (Reidel et al. 1989). The distribution of the basalt flows reflects the tectonic history of the area (Reidel et al. 1989). The basalt is as much as 4,000 m thick in the vicinity of the Hanford Site (Reidel et al. 1989; Glover 1985). The uppermost basalt flow, the Elephant Mountain Member, is at an elevation of about 390 ft under the waste sites. Reidel et al. (1989), Reidel and Fecht (1981), and Rockwell (1979) presented additional information about the Columbia River Basalt Group.

3.2.1.2 Ringold Formation

Ringold sediments predominantly consist of layers of fluvial sand, ancient soils (paleosols), and lacustrine sand, silt, and clay (Lindsey 1996). This formation may be as much as 600 ft thick across the Hanford Site. It consists of uncemented to locally well-cemented clay, silt, fine- to coarse-grained sand, and pebble to cobble conglomerate. Ringold sediments are absent underneath the study area (Williams et al. 2000).

3.2.1.3 Cold Creek Interval (Plio-Pleistocene)

The Plio-Pleistocene unit sediments unconformably overlie the Ringold Formation. This unit is laterally discontinuous. Plio-Pleistocene sediments consist of locally derived basaltic alluvium and pedogenic calcium-carbonate-rich material (Williams et al. 2000). The basaltic material consists of weathered and unweathered locally derived basaltic gravel containing varying amounts of sand and silt. The carbonate-rich sediments consist of calcium carbonate cemented silt, sand, and gravel interfingering with carbonate-poor sediments. Both of these facies may be present at some locations. The Plio-Pleistocene unit generally dips to the south-southwest in the 200 West Area (Slate 1996). DOE (2002d) established the nomenclature for these sediments and referred to them as the Cold Creek Interval.

In the past, the Plio-Pleistocene was divided into an upper silty sand to sandy silt that was designated as early Palouse soil and a lower calcium carbonate-rich interval often referred to as the "caliche layer" (Lindsey et al. 2000). Numerous investigations conducted in the 1990s have observed that the upper unit contains stratified fine sand indicative of lacustrine deposition and not eolian conditions associated with the early Palouse soil (Lindsey et al. 2000). The Plio-Pleistocene unit also contains a series of paleosols with calcium carbonate development indicative of an arid environment (Slate 1996).

The pre-Missoula gravel consists of quartzose to gneissic clast-supported pebble to cobble gravel with quartzo-feldspathic sand matrix that underlies the Hanford formation in the east-central region of the Cold Creek syncline and at the east end of Gable Mountain anticline east and south of the 200 East Area (Williams et al. 2000).

A compact, massive loess-like silt with minor fine-grained sand unit may overlie the Plio-Pleistocene unit. This unit is designated the "Early Palouse soil," and it can range to tens of feet thick. The contact between the Early Palouse sediments and the overlying Hanford formation is gradational. The Early Palouse soil is thickest in the southwest and southeast portions of the 200 West Area, where it reaches a maximum thickness of 65 ft.

3.2.1.4 Hanford Formation

A series of Pleistocene catastrophic flood deposits, informally known as the Hanford formation, overlies the Plio-Pleistocene and older sediments throughout the Hanford Site (Figure 4). The Hanford formation consists of gravel, sand, and silt. The sediments of the Hanford formation are unconsolidated, uncemented, and highly transmissive for the flow of water. This formation is thickest in the central Hanford Site, where it thickens to 350 ft. The Hanford formation is divided into three facies (gravel-dominated, sand-dominated, and silt-dominated) that are gradational with each other. DOE (2002d), Lindsey (1991), Reidel et al. (1992), and Wood et al. (2000a) provided detailed discussions of the Hanford formation lithology.

Interpretations of sediment samples obtained from boreholes in the 200 Areas (Lindsey and Law 1993; Lindsey et al. 1994; and Reidel et al. 1992) have resulted in subdividing the Hanford formation into units (H1a, H1, H2, H2a, H3, and H4). Units H1a, H2a, H3, and H4 are laterally discontinuous, and H3 and H4 are locally identified at the base of the formation (Lindsey et al. 2000). These interpretations have placed the contact between the upper Hanford unit H1 and the intermediate Hanford unit H2 at an elevation of about 615 ft in the area. Hanford H4 is absent.

The rhythmite facies sediments (Hanford H4) were deposited under slack water conditions and in back-flooded areas remote from the main flood channel. These sediments consist of thinly bedded, plane-laminated and ripple cross-laminated silt and fine- to coarse-grained sand and commonly display normally graded rhythmites a few centimeters to several tens of centimeters thick (Baker et al. 1991; DOE 1988). This facies dominates the Hanford formation along the western, southern, and northern margins of the Pasco Basin, within and south of the 200 Areas, and is the lowest sand-dominated facies association.

The Hanford H3 unit (lowest gravel-dominated facies association) consists of pebble and cobble gravel with interbedded sand. The H3 generally consists of coarse-grained basaltic sand and granule to boulder gravel, and ranges from well sorted to poorly sorted. In outcrop, these sediments display massive bedding, planar to low-angle bedding, and large-scale planar cross bedding. The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main flood channel.

The Hanford H2 unit consists of sand-dominated facies with interbedded silt lenses (Lindsey and Law 1993; Lindsey et al. 1994). Some laterally discontinuous silt-rich interbeds are reported in this area, and these high-silt content zones may have higher moisture content and $CaCO_3$ content than the surrounding sand-dominated material. The depositional facies are discontinuous in both horizontal and vertical extents, and little correlation between boreholes has been possible in terms of the minor differences between such features as the silty sand and sandy silt layers (Lindsey and Law 1993; Lindsey et al. 1994).

Unit H1 is dominated by coarse to granule sand and lesser pebble gravel formed from a complex interfingering of gravel and sand-dominated facies (Lindsey and Law 1993; Lindsey et al. 1994). The relative abundance of gravelly facies decreases from the northwest to the south. As gravel content decreases, unit H1 interfingers with the more sand-rich strata of unit H2.

Clastic dikes consisting of layers of silt, sand, and granule gravel crosscut the Hanford formation. These clastic dikes generally crosscut the bedding as alternating vertical to subvertical dikes, although they may locally run parallel to bedding. Clastic dikes also occur in the older sediments (Fecht et al. 1999).

3.2.1.5 Holocene Surficial Deposits

Holocene surficial deposits consist of a mix of silt, sand, and gravel deposited by a combination of eolian and alluvial processes (DOE 1988).

3.2.2 Structure

The Hanford Site is located in the Pasco Basin, which is a physical and structural depression in the Columbia Plateau created by tectonic activity and folding of the Columbia River basalts. The structural framework of the Pasco Basin began developing before Columbia River Basalt Group volcanism (Reidel et al. 1994) and was an area of subsidence that accumulated thick deposits of sediments and volcanic rock. This pattern continued through Columbia River Basalt Group volcanism. Anticlinal ridges were growing under north-south compression. This compression resulted in a series of anticlinal ridges and synclinal valleys with a general east-west trend. The north-south compression and east-west extension have persisted from at least the middle Miocene to the present (Hooper and Camp 1981; Reidel 1984; Hooper and Conrey 1989; Reidel et al. 1989).

The geologic structure of the Pasco Basin area is dominated by a series of east-west-trending anticlines and synclines. Anticlines to the north and south create topographic high areas (Gable Mountain and Rattlesnake Mountain, respectively) with outcropping basalt flows. The Hanford Site 200 Areas are situated on the northern limb of the Cold Creek syncline where bedrock dips to the south at an angle of approximately 5 degrees. Approximately 270 ft of sediments overlie the dipping basalt bedrock in the vicinity of the site.

3.3 Hydrology

During Hanford operations, a significant quantity of liquid effluent was discharged to the soil column in the 200 East Area, causing the water table to rise (PNNL 2001). The water-table elevation (Figure 5) in the northwest 200 East Area peaked at about 409.1 ft (124.7 m) in the late 1980s. In the past, it has been assumed that the general groundwater-flow direction is to the northwest, based on the regional nitrate and ^{99}Tc plume maps (PNNL 1998, 1999); however, more recently, groundwater flow has changed from a northwestern flow to a western flow or southwestern flow (PNNL 2000). The decline in liquid effluent discharges to the soil, especially at B Pond, is expected to cause groundwater flow in the area to reverse direction and resume its pre-Hanford flow toward the southeast (PNNL 2001).

PNNL (2003) and Narbutovskih (1998, 2000) described the hydrology of the Hanford Site and the B-BX-BY WMA. Considerable uncertainty currently exists regarding both velocity and direction of groundwater flow in the vicinity of the B-BX-BY WMA. The water table is nearly flat with a

maximum of 7-inch (in.) change in groundwater elevations across the WMA (Narbutovskih 2000). The top of the unconfined aquifer is currently at an elevation of 401 ft (122.2 meters [m]) and within the Cold Creek Unit. The base of the unconfined aquifer is believed to be the top of the basalt. Aquifer thickness is thin (approximately 5 to 20 ft) in the area. The study area is located in a region of very low hydraulic gradient between the groundwater mound beneath B Pond, which is located east of the 200 East Area and the eastward-moving groundwater from the 200 West Area (Caggiano 1996).

The first appearance of contaminants in the unconfined aquifer was detected in the mid 1950s in groundwater monitoring wells installed around the BY cribs (Knepp 2002). Nitrate, ^{60}Co, and gross beta-emitting contaminants were noted and are attributed to the BY cribs source (Knepp 2002). ^{137}Cs (Thomas et al. 1956) and ^{106}Ru (Clukey 1955; Thomas et al. 1956) were also detected in groundwater. Knepp (2002) indicated that ^{99}Tc was a major contributor to the gross beta measurement. This assertion is at odds with Clukey (1955), which reported "essentially all the total beta activity density to be due to ^{106}Ru," and this difference maybe due to the limitations of the analytical methods available at that time (Clukey 1955). "After the mid 1950s, relatively little tracking of contaminants in groundwater was done until the early 1990s. Discharges to the unconfined aquifer from other sources likely have occurred in this area and commingled with the BY crib discharges. Currently, elevated concentrations (Figure 6) of ^{99}Tc, uranium, cyanide, chromium, tritium, and nitrate are present in local groundwater" (Knepp 2002). Knepp (2002) indicated that concentration contours (Figure 6) for ^{99}Tc, cyanide, uranium, and chromium generally show a northwest to southeast trend, which may indicate the influence of a paleochannel. Williams et al. (2000) mapped a paleochannel in this area as shown on Figure 4.

In June 1996, an assessment groundwater monitoring program was initiated for WMA B-BX-BY when elevated specific conductance was measured in groundwater monitoring well 299-E33-32 (Figure 2), west of the WMA. Elevated specific conductance resulted from increases in nitrate, chloride, sulfate, and sodium concentrations. The June 1996 sample confirmed elevated specific conductance that was initially measured in the February 1996 sampling of the monitoring well. During an expanded Phase I investigation, elevated conductivity was also observed in the February 1997 sample for well 299-E33-41 (Figure 2), east of the BX Tank Farm. Increases in nitrate, chloride, sulfate, and sodium were the cause of the elevated conductivity (Narbutovskih 1998). ^{99}Tc, a non-RCRA co-contaminant, was also identified above previously measured concentrations in the well samples. Northeast of the WMA, significant ^{99}Tc concentrations were detected in wells 299-E33-16 and -18, but very little in wells 299-E33-15, -17, -20, and -39 (Narbutovskih 2000). ^{60}Co has been detected near its quantitation limit (20.49 pCi/L) in wells 299-E33-13 and -16 (Figure 2). Although assessment wells are monitored for ^{137}Cs and ^{90}Sr, there are currently no known occurrences in the groundwater (Narbutovskih 2000). Wells monitoring WMA B-BX-BY have shown elevated levels of ^{99}Tc, nitrate, uranium, cyanide, and chromium along a southeast-northwest trend (Figure 6).

Between 1994 and 2000, an extensive uranium groundwater plume developed in the B-BX-BY WMA. This development is best illustrated by comparing 1994 conditions (Figure 7) as reported by PNNL (1995) with 2000 conditions (Figure 8) as reported by PNNL (2001). In the study area in 1994, groundwater contamination exceeding the proposed maximum concentration level (MCL) of 20 µg/l for uranium was reported only at groundwater well 299-E33-13 (PNNL 1995). "*Prior to 1995, uranium was sampled for the WMA RCRA network wells and select wells in the BY cribs*

managed under the 200-BP-1 CERCLA project. With the exception of well 299-E33-13, the uranium level in most wells was below 10 μg/l. Analyses for uranium were discontinued after early 1995 since the data indicated that, in general uranium was not an issue in the area" (Narbutovskih 1998). Figure 9 is a plot of uranium concentrations measured in groundwater wells in the vicinity of the B-BX-BY WMA that demonstrates the highest levels of uranium were observed in well 299-E33-18 (Figure 2) in January 1994 (Narbutovskih 1998; PNNL 1998; Knepp 2002). Well 299-E33-18 was not sampled for three years following the initial increase in uranium concentrations. Only a limited amount of groundwater samples were collected in the area during 1996. By 1997, the highest reported uranium concentrations in the area were detected in well 299-E33-13 (Figure 9). Uranium had also increased in concentration in well 299-E33-41 by March 1998. Figure 10 illustrates the extent of uranium groundwater contamination in the study area in 2002. At the northwestern edge of the study area, average uranium concentrations in well 299-E33-26 increased from 9.2 μg/l (in 1994, Figure 7) to 180 μg/l (in 2002, Figure 10).

3.4 Description of the B-BX-BY WMA and Adjacent Waste Sites

Located in this study area (Figure 2), the B, BX, and BY Tank Farms have settled and stored hazardous, high-level radioactive mixed wastes while the surrounding waste disposal facilities discharged more than 70 million gallons of liquid radioactive mixed wastes to the soil column. Major waste sites located in this area are the 216-B-7A&B Cribs, 216-B-8 Crib and Tile Field, 216-B-11A&B French Drains, 216-B-35 to -42 Trenches (BX Trenches), 216-B-43 to -50 Cribs (BY Cribs), and the 216-B-57 Crib. Other facilities that may have less impact to the vadose zone include the 216-B-51 French Drain, 241-B-151, -152, -153, and -252 Diversion Boxes, 241-B-301B Catch Tank, 216-BY-201 Settling Tank, and the 244-BX-DCRT and unplanned releases (UPRs). The 216-B-61 Crib was constructed but apparently never used. A brief discussion of each tank farm and waste site is included in the following sections. Figure 2 provides the locations of each site. Because of their number, lack of borehole coverage, and the generally small amount of waste lost to the vadose zone, the UPRs will not be discussed further.

3.4.1 B-BX-BY WMA

The B, BX, and BY Tank Farms and associated infrastructure comprise WMA B-BX-BY (Figure 2). These tanks were built to settle and store high-level radiological waste generated from chemical processing of irradiated uranium fuel. The B and BX Tank Farms represent first-generation tank designs, while the BY Tank Farm represents the second-generation tank design.

Constructed in 1943-44, the B Tank Farm (Figure 12) consists of twelve 100-series tanks (241-B-101 to 241-B-112), each with a capacity of 538,000 gallons, and four 200-series tanks (241-B-201 to 241-B-204), each with a capacity of 55,000 gallons. The tanks were constructed by excavating the entire area of the tank farm, building the tanks, and then backfilling around the tank structures. Each tank consists of a reinforced concrete structure with an inner steel plate liner on the bottom and sides.

The 100-series tanks are 75 ft in diameter. The bottom is dished, with the center 1 ft lower than the perimeter. The steel liner extends 18 ft above the base at the perimeter. An unlined reinforced concrete dome covers the tank 12 ft above the top of the liner, such that the total height of the tank is 33 ft. The entire structure is covered with 6 to 9 ft of backfill material. In B Tank Farm, the base of the excavation (~614 ft elevation) is approximately 42 ft below grade. The twelve tanks are arranged in four three-tank cascade series, with successive tanks 1 ft lower than the previous tank. The

cascade lines connecting the tanks are located 1.5 ft below the top of the liner; the maximum waste level in each tank is maintained at 16 ft, or about 2 ft below the top of the liner. In each cascade series, the first tank fills and then overflows through the cascade line to the next tank.

The 200-series tanks are 20 ft in diameter, and the steel liner extends to 25 ft above the base. The bottoms are dished, with the center 0.5 ft lower than the perimeter. The four tanks are located at the same elevation and connected by tie lines that allow overflow from one tank to another.

In the B Tank Farm, seven of the twelve 100-series tanks and three of the four 200-series tanks are designated as confirmed or assumed leakers, with an estimated aggregate leak volume of 53,900 gallons (Hanlon 2003).

The BX Tank Farm (Figure 13) was constructed in 1946-47. It contains twelve 100-series tanks identical to those in the B Tank Farm. The base of the excavation (~617 ft elevation) is approximately 43 ft below grade. Of the twelve 100-series tanks in the BX Tank Farm, five are designated leakers, with an estimated total leak volume of 96,500 gallons (Hanlon 2003).

The BY Tank Farm (Figure 14) was constructed in 1948-49 and placed into service in 1950 as an extension of the B Tank Farm. It contains twelve 100-series tanks with a capacity of 758,000 gallons. Depressions below grade were backfilled with concrete. Concurrent with tank construction (Figure 14), as the sides were being built, the original excavated material was uniformly backfilled around the tanks in 0.5- to 2-ft-thick layers and compacted. The tanks are similar to those in the B and BX Tank Farms, except the liner extends to 24 ft above the base, and the tank structure is about 40 ft high. Each three-tank cascade in the BY Tank Farm is connected to the corresponding series in the BX Tank Farm. The BY Tank Farm was constructed in an area where the ground surface sloped to the north. After tank construction was completed, an additional volume of approximately 10,000 cubic yards of backfill material was required to provide adequate soil cover. The base of the excavation (~603 ft elevation) is approximately 50 ft below finished grade. Five of the twelve tanks in BY Tank Farm are designated as confirmed or assumed leakers, with an estimated aggregate leak volume of 41,100 gallons (Hanlon 2003).

All of the tanks in the B-BX-BY WMA have been removed from service and are designated stabilized. In addition, all of the tanks are designated to be in an intrusion prevention status, meaning that they have undergone measures to minimize the potential for addition of liquids to the tanks (Hanlon 2003).

The majority of the vadose monitoring boreholes in the B, BX, and BY Tank Farms were drilled in the early to mid 1970s and completed with 6-in.-diameter carbon steel casing. These boreholes were routinely logged with gross gamma logging equipment for leak-detection purposes. The 52 monitoring boreholes in the B Tank Farm were drilled to depths between about 100 and 135 ft (~556 and ~521 ft elevation). The 74 monitoring boreholes in the BX Tank Farm were typically drilled to a depth of 100 ft (~560 ft elevation). In 1970, 19 boreholes were drilled on the east side of the tank farm to investigate a spill near tank BX-102 (Womack and Larkin 1971). The majority of the boreholes in the BY Tank Farm are 100 ft deep (~553 ft elevation), well above the groundwater. A few boreholes around the perimeter of the BY Tank Farm extend to depths of 150 ft (~503 ft elevation).

In addition to the waste storage tanks, there are ancillary structures within the B-BX-BY WMA that were associated waste storage and disposal operations. The most significant are described below.

The 241-B-252 Diversion Box, located on the west side of B Tank Farm, transferred waste solutions from processing and decontamination operations between 1945 and June 1984. This unit is connected to the 241-BX-154 and 241-B-152 Diversion Boxes and the B and BY Tank Farms. The box consists of a 2-ft-thick, walled, reinforced concrete structure 36 ft long by 9 ft wide by 15.27 ft deep. The top of the box is a concrete cover block that extends a few inches above grade. Diversion boxes and receiving vaults drain to catch tanks or single-shell tanks.

The 241-B-301B Catch Tank is located in the B Tank Farm (Figures 2 and 12) approximately 30 ft south of the 241-B-252 Diversion Box. The tank collected waste spilled in the 241-B-151, 241-B-152, 241-B-153, and 241-B-252 Diversion Boxes during waste transfers. It was in service from 1945 until 1984. Its contents are unknown and it was isolated in 1985 (DOE 1993a).

The 244-BX DCRT is an active waste management unit located in the east side of the BX Tank Farm. The unit last received waste from the BY-102 and -109 single-shell tanks (BY Tank Farm) during the 1991 stabilization campaign (DOE 1993a). The 244-BX-DCRT is constructed of carbon steel with a 31,000-gallon design capacity. The tank sets lengthwise in a reinforced concrete, steel-lined vault. The lowest portion of the vault that houses the tank is about 28 ft below grade.

3.4.2 Waste Sites West of the B-BX-BY WMA

The 216-B-35 through 216-B-42 Trenches (Figure 2), which are located approximately 200 ft (60 m) west of the BX Tank Farm, were designed to percolate waste liquid into the ground. Under the concept of "specific retention," the trenches were designed to utilize the moisture retention capacity of the vadose zone sediments. The intent was to limit the volume of liquid disposed to each trench to 10 percent of the packed soil volume between the bottom of the trench and the groundwater table (Haney and Honstead 1958). Each trench was 252 ft (77 m) long, 10 ft (3 m) wide, and 10 ft (3 m) deep (~655 ft elevation). The side slopes of the excavations were at a ratio of 1.5:1. Trending east-west, they are unlined excavations that were used for a short period of time (less than 1 year). Aboveground pipelines were removed and the trenches were backfilled when the waste disposal capacity was reached. Figure 11 is a 1954 photograph that shows discharge to a trench. Waste streams were intentionally discharged to specific retention trenches during 1953 and 1954.

3.4.3 Waste Sites Northeast of the B-BX-BY WMA

The 216-B-7A&B Cribs are located approximately 50 ft north of the B Tank Farm. The 216-B-7A&B Cribs consist of two parallel wooden structures connected by underground piping. The two cribs are located about 20 ft apart and are in line with a "T" inlet pipe that supplied waste to both cribs simultaneously from the 201-B settling tanks (241-B-201, 241-B-202, 241-B-203, and 241-B-204). Process effluent from the 221-B and 224-B Buildings was routed to the settling tanks (B-201 to B-204) from 1946 through 1967 and overflowed to the cribs. The cribs were reactivated and used intermittently from December 1954 through May 1967, when it was determined that they had reached their radionuclide disposal capacity (WIDS). Each crib is a 12-ft by 12-ft by 4-ft wooden structure made of 6-in. by 6-in. timbers, placed in a 14-ft by 14-ft by 14-ft-deep excavation (~639 elevation).

The 216-B-8 Crib and Tile Field are located about 350 ft north of the B Tank Farm. The crib is a 12-ft by 12-ft wooden structure in a 14-ft by 14-ft by 22.5-ft-deep excavation (~620 ft elevation). The structure is hollow and not gravel filled. The tile field is 300 ft long, 100 ft wide, and fed by a

12-in. vitrified clay pipe trunk with eight pipes branching at 45 degrees. The piping is placed over 4 ft of gravel with 6 in. of gravel above the piping. The bottom of the tile field excavation is 4 ft below grade and the sides of the excavation are sloped at a ratio of 1:1.5. Piping connected the unit to the B-110, -111, and -112 single-shell tanks in the B Tank Farm. After the 216-B-5 Reverse Well was taken out of service, the 216-B-8 Crib was used. Sludge accumulated in the crib, decreasing its infiltration capacity. The tile field was then placed into service to receive the waste overflow from the crib.

The 216-B-11A&B French Drains (Figure 2) are located approximately 250 ft north of the B Tank Farm. These two facilities are placed about 60 ft apart in line with a 3-in. steel inlet pipe. Each well consists of 2-ft-diameter by 30-ft-long corrugated steel culvert buried vertically, 10 ft below the ground surface (bgs) to a total depth of 40 ft bgs (~608 ft elevation). The culverts are perforated on 6-in. centers at 12-in. vertical intervals. The French drains received waste from the 242-B Evaporator and were deactivated when it became evident that cribs and trenches were a more effective means of waste disposal.

The 216-B-51 French Drain is an inactive waste management unit located about 750 ft north of the B Tank Farm. This unit consists of vertically stacked sections of 5-ft-diameter concrete pipe filled with gravel. The bottom of the unit is 14 ft below grade. The French drain received drainage from the pipeline that transferred tributyl phosphate (TBP) waste from the BY Tank Farm to the BC Cribs and Trenches. The drain was active from January 1956 to January 1958.

3.4.4 Waste Sites Northwest of the B-BX-BY WMA

The 216-B-43 to -50 Cribs are located approximately 200 ft north of the BY Tank Farm. Each of the eight cribs were constructed of four 4-ft-diameter by 4-ft-long concrete culverts buried vertically, 7 ft below grade, on a 5-ft-thick bed of gravel. The culverts are arranged in a square pattern with the centers spaced 15 ft apart in a 30-ft by 30-ft by 15-ft-deep excavation (~615 ft elevation). Each culvert is fed by an 8-in. steel pipe originating from a main in a chevron pattern. Each culvert has a concrete cover. The cribs were constructed to receive scavenged TBP waste.

The BY Cribs were closed to waste disposal when ^{60}Co and ^{137}Cs contamination breakthrough to groundwater occurred at the 241-BY-11 (currently designated as 299-E33-3) well on January 9, 1956 (Thomas et al. 1956). The travel time was estimated to be between 10 days and two months (Clukey 1955). A groundwater sample collected in February 1956 from well 241-BY-12 (currently 299-E33-4) contained previously undetected ^{60}Co that exceeded the 1956 limits for groundwater contamination by a factor of three hundred. A well (currently 299-E33-17) located about 1,000 ft southeast from the BY Cribs site was also contaminated but the concentrations were below the limits. It was determined the total volume of waste disposed of at the BY Cribs would have been reduced by approximately 50 percent if it had been known earlier that ^{60}Co existed in the groundwater (Thomas et al. 1956).

The 216-B-50 Crib received condensate from the BY Tank Farm ITS system located in the BY Tank Farm. The decision to use the 216-B-50 Crib for ITS condensate was made about 8 or 9 years after the closure of the other cribs when monitoring showed that the groundwater radioactivity levels were definitely decreasing (WIDS).

The 216-B-57 Crib consists of a 12-in.-diameter corrugated and perforated pipe within an excavation 200 ft long by 15 ft wide by 10 ft deep (Szwartz 1996). The side slopes of the excavation were at a

ratio of 1.5:1. The pipe was placed in the excavation following placement of a 4-ft-thick layer of gravel. This type of structure was also known as an enclosed trench. In 1994, the site was covered with the Hanford Prototype Barrier. The barrier is 340 ft long, 210 ft wide, and attains a maximum height of 49 ft above the original ground surface. The total surface area of the barrier is 6.2 acres.

The 216-BY-201 Flush Tank received TBP waste via the BY Tank Farm that was subsequently released to the 216-B-43 to -49 Cribs. The flush tank is a rectangular, reinforced concrete disposal structure. The unit was designed to scavenge the TBP waste and discharge the supernatant to the 216-B-43 to -49 Cribs.

The 216-B-61 Crib was built to receive intermediate level process condensate from the In Tank Solidification (ITS) unit when the 216-B-50 Crib reached its radionuclide capacity. However, available records indicate that the 216-B-61 Crib was never used.

3.5 Operational History

The B, BX, BY Tank Farms and adjacent waste sites have received waste generated by a variety of major chemical processing operations. Wood et al. (2000a) provided a discussion of the operations and wastes transferred to selected waste sites in the study area. Table 3-1 provides a general summary of the sites and associated wastes, and Table 3-2 presents an estimate of releases of various radionuclides.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

Site	Time in Use	Estimate of Volume (m^3) Released	Source	Type of Waste
B Tank Farm				
B-101	1945-1974	18.9	B Plant	Metal waste, coating, high- & low-level wastes, evaporator bottoms, and wastewater.
B-102	1945-1978	0	B Plant and PUREX	Metal waste, coating waste, low-level waste, evaporator feed and bottoms waste, ion-exchange waste, cladding waste, and wastewater.
B-103	1945-1978	0 (Assumed Leaker, Hanlon 2003)	B Plant REDOX N-Reactor Battelle Northwest Laboratory 224-U PUREX	Metal waste, coating waste, low-level waste, evaporator feed and bottoms waste, ion-exchange waste, decontamination waste, laboratory waste, organic wash waste, tri-butyl phosphate waste, cladding waste, and wastewater.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

Site	Time in Use	Estimate of Volume (m^3) Released	Source	Type of Waste
B-104	1946-1978	0	242-B Evaporator U Plant	First- and second-cycle waste, evaporator bottoms waste, evaporator salt-cake waste, first-cycle sludge, and wastewater.
B-105	1947-1978	11.4	242-B Evaporator	First- and second-cycle waste, evaporator bottoms waste, evaporator salt-cake waste, and wastewater.
B-106	1947-1978	0	B Plant Battelle Northwest Laboratory 224-U, U Plant Hanford Laboratory Operations	First- and second-cycle waste, low-level waste, evaporator feed and bottoms waste, ion-exchange waste, TBP waste, and wastewater.
B-107	1945-1978	53.1	PUREX 242-B Evaporator U Plant	First-cycle waste, TBP waste, coating waste, evaporator bottoms waste, uranium recovery waste, cladding waste, evaporator salt-cake waste, and wastewater.
B-108	1945-1978	0	PUREX 242-B Evaporator U Plant	First-cycle waste, evaporator feed and bottoms waste, ion-exchange waste, coating waste, evaporator salt-cake waste, cladding waste, and wastewater.
B-109	1946-1978	0	PUREX B Plant 242-B Evaporator U Plant, 224-U	First-cycle waste, evaporator feed and bottoms waste, ion-exchange waste, coating waste, evaporator salt-cake waste, cladding waste, and wastewater.
B-110	1945-1975	94.7	B Plant PUREX	First- and second-cycle waste, high- & low-level waste, evaporator bottoms waste, fission product waste, ion-exchange waste, decontamination waste, in-tank solidification waste, cesium recovery waste, salt-cake waste, and wastewater.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

Site	Time in Use	Estimate of Volume (m^3) Released	Source	Type of Waste
B-111	1945-1976	0 (Assumed Leaker, Hanlon 2003)	B Plant PUREX	First- and second-cycle waste, evaporator bottoms waste, fission product waste, ion-exchange waste, decontamination waste, high-level waste, cesium recovery waste, concentrated bottoms, recycle waste, and wastewater.
B-112	1946-1978	0 (Assumed Leaker, Hanlon 2003)	B Plant	First- and second-cycle waste, low-level waste, decontamination waste, evaporator feed and bottoms waste, ion-exchange waste, fission product waste, concentrated feed waste, and wastewater.
B-201	1952-1975	4.54	224-U	Metal waste and wastewater.
B-202	1951-1978	0	224-U B Plant	Metal waste and high-level waste.
B-203	1952-1976	1.14	224-U	Metal waste.
B-204	1952-1976	1.51	224-U	Metal waste.
BX Tank Farm				
BX-101	1948-1972	15.1	B Plant REDOX N Reactor U Plant PUREX	$BiPO_4$ metal waste, low-level and ion-exchange wastes, coating waste, evaporator bottoms waste, organic wash waste, TBP waste, acid concentrator wastes, double-shell slurry feed waste, cesium recovery waste, and ITS salt cake.
BX-102	1948-1971	348	B Plant U Plant	$BiPO_4$ metal waste, low-level waste, coating waste, evaporator bottoms waste, organic wash waste, TBP waste, and diatomaceous earth.
BX-103	1948-1977	0	B Plant REDOX N Reactor PUREX U Plant Battelle Laboratory	$BiPO_4$ metal waste, high- & low-level and ion-exchange wastes, coating waste, evaporator feed and bottoms wastes, organic wash waste, acid concentrator, and TBP waste.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

Site	Time in Use	Estimate of Volume (m^3) Released	Source	Type of Waste
BX-104	1949-1980	0	B Plant REDOX U Plant	$BiPO_4$ metal waste, high- & low-level and ion-exchange wastes, coating waste, evaporator feed and bottoms wastes, TBP waste, double-shell slurry feed waste, cesium recovery waste, and ITS salt cake.
BX-105	1949-1980	0	B Plant U Plant	$BiPO_4$ metal waste, ion-exchange waste, coating waste, evaporator feed and bottoms waste, TBP waste, and double-shell slurry feed.
BX-106	1949-1977	0	B Plant REDOX U Plant	$BiPO_4$ metal waste, low-level and ion-exchange wastes, coating waste, evaporator feed and bottoms wastes, organic wash waste, and TBP waste.
BX-107	1948-1977	0	B Plant U Plant	$BiPO_4$ first-cycle waste, ion-exchange waste, evaporator feed waste, and TBP waste.
BX-108	1949-1977	0 (Assumed Leaker, Hanlon 2003)	BY Tank Farm C Tank Farm U Plant	$BiPO_4$ first-cycle waste, coating waste, ion-exchange waste, and TBP waste.
BX-109	1950-1977	0	U Plant	$BiPO_4$ first-cycle waste, coating waste, ion-exchange waste, TBP waste, uranium recovery waste, and cesium recovery waste.
BX-110	1949-1977	0 (Assumed Leaker, Hanlon 2003)	PUREX	$BiPO_4$ first-cycle waste, coating waste, ion-exchange waste, evaporator bottoms waste, ITS bottoms waste, and cesium recovery waste.
BX-111	1950-1977	15.1	PUREX	$BiPO_4$ first-cycle waste, coating waste, evaporator feed and bottoms waste, ion-exchange waste, and ITS bottoms waste.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

Site	Time in Use	Estimate of Volume (m^3) Released	Source	Type of Waste
BX-112	1950-1977	0	U Plant	$BiPO_4$ first-cycle waste, coating waste, evaporator feed and bottoms waste, ion-exchange waste, and TBP waste.
BY Tank Farm				
BY-101	1950-1977	0	B Plant BX Farm Cascade BY Transfers C Farm Transfers	Metal waste, coating waste, TBP waste, and ITS bottoms and recycle waste.
BY-102	1950-1977	0	B Plant BX Farm BY Transfers	Metal waste, coating waste, TBP waste, and ITS bottoms and recycle waste.
BY-103	1950-1974	0 (Assumed Leaker, Hanlon 2003)	B Plant BX Farm BY Transfers	Metal waste, coating waste, organic wash waste, TBP waste, and ITS bottoms and recycle waste.
BY-104	1950-1977	0	B Plant BX Farm Cascade	Metal waste, coating waste, TBP waste, evaporator feed and bottoms waste, and ITS bottoms and recycle waste.
BY-105	1951-1977	0 (Assumed Leaker, Hanlon 2003)	B Plant BY Transfers	Metal waste, coating waste, TBP waste, and ITS bottoms and recycle waste.
BY-106	1953-1977	0 (Assumed Leaker, Hanlon 2003)	B Plant BY Transfers C Farm Transfers	First-cycle waste, metal waste, coating waste, TBP waste, evaporator bottoms waste, and ITS bottoms and recycle waste.
BY-107	1950-1976	0 (Assumed Leaker, Hanlon 2003)	B Plant U Plant BX Farm Cascade	First-cycle waste, metal waste, coating waste, TBP waste, and ITS bottoms and recycle waste.
BY-108	1951-1977	0 (Assumed Leaker, Hanlon 2003)	B Plant U Plant C Farm Transfers	First-cycle waste, metal waste, coating waste, TBP waste, and ITS bottoms and recycle waste.
BY-109	1953-1980	0	B Plant U Plant BY Farm Transfers B Farm Transfers C Farm Transfers	Metal waste, coating waste, TBP waste, organic wash waste, evaporator bottoms waste, and ITS bottoms and recycle waste.
Site (Operable Unit)	**Time in Use**	**Estimate of Volume (m^3) Released**	**Source**	**Type of Waste**
BY-110	1952- 1979	0	BX Farm Cascade B Plant U Plant	First-cycle waste, TBP waste, coating waste, and ITS bottoms and recycle waste.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

BY-111	1952- 1977	0	B Plant BY Farm Transfers C Farm Transfers	Metal waste, coating waste, TBP waste, organic wash waste, evaporator feed and bottoms waste, and ITS bottoms and recycle waste.
BY-112	1952- 1977	0	B Plant U Plant BY Farm Transfers C Farm Transfers	Metal waste, coating waste, TBP waste, and ITS bottoms and recycle waste.
BY-201	Unknown	11,000 gal spill (WIDS)		Scavenged uranium recovery from U Plant.
Waste Sites Northwest of the B-BX-BY WMA				
216-B-43 Crib (200-TW-1)	Nov. 1954	2,100	221-U Building	Scavenged uranium recovery from U Plant.
216-B-44 Crib (200-TW-1)	Dec. 1954 - Mar. 1955	5,600	221-U Building	
216-B-45 Crib (200-TW-1)	Apr.-June 1955	4,910	221-U Building	
216-B-46 Crib (200-TW-1)	Sept.-Dec. 1955	6,700	221-U Building	
216-B-47 Crib (200-TW-1)	Sept. 1955	3,700	221-U Building	
216-B-48 Crib (200-TW-1)	Nov. 1955	4,090	221-U Building	
216-B-49 Crib (200-TW-1)	Nov.-Dec. 1955	6,700	221-U Building	
216-B-50 Crib (200-PW-5)	Jan. 1965-1974	Not estimated 54,800 from DOE (1993a)	BY Tank Farm	Storage tank condensate from ITS-1.
216-B-57 Crib (200-PW-5)	Feb. 1968-June 1973	Not estimated 84,400 from DOE (1993a)	BY Tank Farm	Storage tank condensate from ITS-2.
216-B-61 Crib (200-MW-1)	Not used	216-B-61 Crib	Not used	216-B-61 Crib
Waste Sites Northeast of the B-BX-BY WMA				
216-B-7A & -7B Cribs (200-TW-2)	10/1946 - 05/1967	43,400	224-B	224-B facility wastes, 5-6, decon waste.
216-B-8 Crib and Tile Field (200-TW-2)	04/1945 - 12/1951	27,200	221-B, 224-B	2C, 5-6, decon waste, 1C condensate.
216-B-51 French Drain (200-TW-1)	01/1956 - 01/1958	0.9	Flush drainage from BC Crib pipeline	Scavenged TBP waste DOE (1993a).
Site (Operable Unit)	**Time in Use**	**Estimate of Volume (m^3) Released**	**Source**	**Type of Waste**
216-B-11A&B French Drains (200-PW-5)	12/1951 - 12/1954	29,600	242-B Evaporator	1C condensate, laboratory waste.
Waste Sites (BX Trenches) West of the BX Tank Farm				
216-B-35	02/1954 – 03/1954	1560	221-B Building	First-cycle supernatant.

Table 3-1. Summary of the Operational History for the B-BX-BY WMA and Adjacent Waste Sites

(200-TW-2)				
216-B-36 (200-TW-2)	03/1954 – 04/1954	1940	221-B Building	First-cycle supernatant.
216-B-37 (200-TW-2)	08/1954	4330	242-B-42 Waste Evaporator	Evaporator bottoms from 242-B Evaporator.
216-B-38 (200-TW-2)	07/1954	1430	221-B Building	First-cycle supernatant.
216-B-39 (200-TW-2)	12/1953 –11/1954	1470	221-B Building	First-cycle supernatant.
216-B-40 (200-TW-2)	04/1954 – 07/1954	1640	221-B Building	First-cycle supernatant.
216-B-41 (200-TW-2)	11/1954	1440	221-B Building	First-cycle supernatant.
216-B-42 (200-TW-1)	01/1955-02/1955	1,500	221-U Building	Scavenged TBP waste; uranium recovery waste from U Plant.
References:	DOE (1993a) DOE (1998a) DOE (2000a)	Bergeron et al. (2001)	Waite (1991) DOE (1998a) DOE (2000a)	Doud (1964) Anderson (1990) Waite (1991) DOE (1997a) DOE (1998a) DOE (2000a)

Table 3-2. Summary of Median Radionuclide Release Estimates for the B-BX-BY WMA and Adjacent Waste Sites

Waste Site	^{137}Cs (Median Estimate in Curies)	^{154}Eu (Median Estimate in Curies)	^{60}Co (Median Estimate in Curies)	U (total) (Median Estimate in kg)	^{90}Sr (Median Estimate in Curies)	^{99}Tc (Median Estimate in Curies)
B Tank Farm						
B-101	0.16	2.15	0.0714	0.393	645	0.212
B-103	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
B-105	180	0.00575	0.0022	11.1	237	0.0691
B-107	1420	0.974	0.052	46.2	283	0.43
B-110	16000	34.6	2.61	103	3900	13.8
B-111	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
B-112	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
B-201	1.81	7.86E-05	4.90E-06	0.71	1.6	0.000106
B-203	2.17	9.49E-05	5.91E-06	0.857	1.92	0.000128
B-204	0.0024	1.04E-07	6.51E-09	0.000946	0.00212	1.41E-07
UPR-200-E-109	1.85	7.67E-05	3.58E-05	1.13	15.5	0.00114
Waste Site	**^{137}Cs (Median Estimate in Curies)**	**^{154}Eu (Median Estimate in Curies)**	**^{60}Co (Median Estimate in Curies)**	**U (total) (Median Estimate in kg)**	**^{90}Sr (Median Estimate in Curies)**	**^{99}Tc (Median Estimate in Curies)**
BX Tank Farm						
BX-101	176	3.45	0.2	4.43	673	1.1
BX-102	3530	2.4	0.124	9430	2960	3.27
BX-108	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
BX-110	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
BX-111	51.7	0.0437	0.00221	14.2	45.1	0.015
BY Tank Farm						
BY-103	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					

Table 3-2. Summary of Median Radionuclide Release Estimates for the B-BX-BY WMA and Adjacent Waste Sites

BY-105	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
BY-106	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
BY-107	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
BY-108	Assumed leaker (Hanlon 2003); inventory not estimated in Simpson et al. (2001).					
Waste Sites North of BY Tank Farm						
216-B-43	468	25.5	0.0001	115	497	10.1
216-B-44	1230	6.7	0.0002	308	1290	26.9
216-B-45	1090	5.9	0.0002	267	1150	23.5
216-B-46	1510	8.0	0.0003	364	1580	32.3
216-B-47	818	4.4	0.0001	203	872	17.8
216-B-48	922	4.9	0.0002	223	958	19.7
216-B-49	1480	8.0	0.0003	367	1570	32.2
216-B-50	Inventory not estimated in Simpson et al. (2001).					
216-B-57	Inventory not estimated in Simpson et al. (2001).					
216-B-61	None					
Waste Sites Northeast of the B-BX-BY WMA						
216-B-7A&B Cribs	8500	0.375	0.02	2750	6210	0.51
216-B-8 Crib and Tile Field	5370	0.24	0.02	1730	3960	0.32
216-B-51 French Drain	0.22	0.0012	3.90E-08	0.00002	0.02	0.0048
216-B-11A&B French Drains	18	N/A[1]	N/A	.01	1.9	.007
Waste Sites (BX Trenches) West of the BX Tank Farm						
216-B-35	394	1.49	0.0782	52.1	26.3	2.02
216-B-36	489	1.86	0.0972	64.4	32.5	2.51
216-B-37	66,400	14.4	0.807	4080	87,100	25.5
216-B-38	362	1.37	0.0717	48.0	23.7	1.84
216-B-39	371	1.41	0.0735	49.6	24.9	1.90
216-B-40	415	1.57	0.0821	54.4	27.3	2.11
216-B-41	365	1.38	0.0722	47.9	23.9	1.86
216-B-42	334	1.79	5.91×10^{-5}	81.5	346	7.21
Reference: Simpson et al. (2001). Radionuclides are decayed to January 1, 1994.						

[1] N/A – not applicable

3.6 Previous Investigations

The Hanford Tank Farms Baseline Characterization Project (DOE 1997a, 1998a, 2000a, 2000b, 2000c, and 2000d) and the Hanford 200 Areas Spectral Gamma Baseline Characterization Project (DOE 2002a, 2002b, and 2003a) have provided assessments of these tank farms and waste sites based on spectral gamma logging and are discussed in this section. In addition, the Hanford Tank Farms Vadose Zone Monitoring Project (DOE 2003f) is ongoing and compares recent gamma activity data collected against the tank farm baseline to assess changes of contaminant distribution in the vadose zone. Information regarding the existing geophysical logs and nature and extent of subsurface contamination in the B-BX-BY WMA and adjacent waste sites are presented in tank summary data reports, tank farms reports, and waste site summary reports. Appendix A lists baseline documents relevant to the B-BX-BY WMA and adjacent waste sites.

Log plots and Log Data Reports for all SGLS logging are available on the Internet at **http://www.gjo.doe.gov/programs/hanf/HTFVZ.html**.

Previous investigators have provided general assessments of the waste sites and tank farms based on gross gamma logging and spectral gamma logging. Geophysical logging of monitoring wells and boreholes was conducted in the 1950s at the facilities related to B Plant operations. Gross gamma logging has been used as a secondary tank leak monitoring system (Isaacson and Gasper 1981). Several evaluations of the log data for the waste sites were performed, including Raymond and McGhan (1964) and Fecht et al. (1977). DOE (1993a) provided comprehensive descriptions of these studies, a discussion of gross gamma logging methodology, and interpretations of the data. DOE (1993a) also presented an evaluation of individual waste units such as cribs, ponds, trenches, and ditches. DOE (2003b) evaluated several of the individual waste sites as part of the analogous site approach. The *Phase I Remedial Investigation Report for 200-BP-1 Operable Unit* (DOE 1993b) reported results of geophysical logging and soil sample results for the BY Cribs. Womack and Larkin (1971) investigated the leak at tank BX-102. As a prelude to the WMA B-BX-BY Field Investigation Report (Knepp 2002), historic gross gamma logging data were assessed for the three farms in the WMA (Randall and Price 1998; Myers 1999a, 1999b; Randall et al. 2000). A synopsis of this previous work is presented in this section.

Raymond and McGhan (1964) provided gross gamma logs from a scintillation detector in *"representative wells adjacent to waste disposal sites. Logs of wells that show no ground contamination are not included*." The scintillation detector system had a lower detection limit reported as about 3 pCi/cc (^{106}Ru - ^{106}Rh). Log data between 1957 and 1974 were acquired with a similar detection system but with at least three modifications. These modifications generally were to improve system sensitivity and to reduce noise. The profile of the gamma count rate is not changed significantly by these modifications, so that comparisons over time may be made.

The advent of high-resolution spectral gamma logging in the 1990s has allowed identification and quantification of gamma-emitting radionuclides in the subsurface. Brodeur et al. (1993) provided summaries of several waste units that included waste discharge histories, plan views of the sites, and geophysical log data acquired in the monitoring boreholes. Price (1998) and Horton and Randall (2000) did limited investigations of selected waste sites and boreholes in the 200 East Area. Knepp (2002) also evaluated the spectral gamma data for the B-BX-BY WMA. A synopsis of this information is presented in this section.

The B-BX-BY Field Investigation Report (Knepp 2002) focused on the area east of tank BX-102 (BX Tank Farm) and northeast of tank B-110 (B Tank Farm). These two areas were investigated by drilling two new boreholes to groundwater and evaluating existing borehole data including groundwater and geophysical data. The major conclusion of the B-BX-BY Field Investigation Report (Knepp 2002) was that: "*The future impacts from wastes currently in the vadose zone that resulted from past releases from the B, BX, or BY Tank Farms are not expected to exceed drinking water standards as long as high volume liquid discharges to the vadose zone are eliminated*." With regards to the nearby waste sites, Knepp (2002) concluded, "*Complex hydraulic processes play a major role in contaminant movement in WMA B-BX-BY. Strong evidence of extensive vadose zone lateral migration in the WMA exists. Lateral migration may have extended into WMA B-BX-BY from adjacent past practice discharge sites. Ponding of runoff from natural precipitation in the WMA may have added significant amounts of spatially confined infiltration. Changes in groundwater flow direction have caused plumes from other sources to be found under the WMA*."

The Remedial Investigation Report for 200-TW-1 and 200-TW-2 Operable Units (includes the 200-PW-5 OU) (DOE 2003b) included characterization activities associated with four representative waste sites that exist in the study area of this summary report. These sites were the 216-B-46 Crib, 216-B-38 Trench, 216-B-57 Crib, and 216-B-7A Crib. Results of model studies cited in this report indicate that the only radiological contaminants from the -7A Crib that will reach groundwater in excess of MCLs are the uranium isotopes. The elevated levels of ^{238}U (108 pCi/g) associated with the -7A Crib were detected between elevations of 623.5 and 620 ft (29.5 and 33 ft bgs) in the vadose zone. The report estimated that uranium isotopes will require more than 100 yrs to reach the water table. Modeling of the 216-B-38 Trench also suggested the uranium isotopes are the only radiological constituent that will reach groundwater in excess of MCLs. Model results suggested that uranium will not arrive at the water table for several hundred years, if at all (DOE 2003b). Modeling at the 216-B-46 Crib suggested that ^{238}U breaks through to groundwater almost immediately (at less than 1.0 E-06 pCi/L), although the peak concentration (approximately 300 pCi/L) is not expected to occur until near the end of the 1,000-yr simulation period, when the concentration appears to be stabilizing.

3.6.1 B-BX-BY WMA

The Hanford Tank Farms Baseline Characterization Project (DOE 1997a, 1998a, 2000a, 2000b, 2000c, and 2000d) provided assessments of the tank farms in the WMA based on spectral gamma logging. These assessments are discussed in Sections 3.6.1.1, 3.6.1.2, and 3.6.1.3. Analysis of historical gross gamma logging records (Randall and Price 1998; Myers 1999a, 1999b; Randall et al. 2000) identified several boreholes in the B-BX-BY WMA where changes in the gamma activity appear to be taking place over time. In the BY Tank Farm (Myers 1999b), ^{60}Co was detected moving downward at approximately 1 to 2 ft/year in several boreholes, and 26 boreholes were classified as having "unstable conditions" (changes that could not be explained by radioactive decay). All of these boreholes were located near tanks that are suspected leakers (as identified by Hanlon 2003), except for boreholes 22-11-01 (299-E33-126) and 22-10-07 (299-E33-254), which are located near tanks BY-111 and BY-110, respectively. In the BX Tank Farm (Myers 1999a), 14 boreholes located near tanks BX-101 through BX-105 were classified as having "periods of instability". In the B Tank Farm (Randall et al. 2000), only two zones were determined to be unstable near tank B-110. The most mobile species appeared to be ^{60}Co, ^{106}Ru, and ^{125}Sb, although movement of ^{137}Cs was also identified (Wood et al. 2000a).

Since July 2001, 123 boreholes in the B-BX-BY WMA have been monitored with the Radionuclide Assessment System (RAS), which is a gamma-ray logging system. Table 3-3 lists the borehole number, tank, baseline log date, and the RAS monitoring event dates. A comment is also included that describes results of the comparison with previously collected log data. In general, no significant changes in radionuclide contaminant distribution have been observed since 2001.

Table 3-3. Results of the Hanford Tank Farms Vadose Zone Monitoring for WMA B-BX-BY

Borehole Number	Tank	Baseline SGLS Log	RAS Event A	RAS Event B	RAS Event C	RAS Event D	RAS Event E	Comment
20-00-05	B-101	08/21/97	05/29/02	04/14/03				No apparent change
20-01-01	B-101	08/20/97	05/28/02	04/14/03				No apparent change
20-01-06	B-101	08/26/97	05/29/02	04/08/03				No apparent change
20-03-06	B-103	05/06/99	09/23/02					No apparent change
20-02-09	B-105	09/16/97	09/23/02					No apparent change
20-05-06	B-105	08/25/97	09/25/02					No apparent change
20-06-03	B-106	11/18/98	05/28/02	04/21/03				No apparent change
20-06-06	B-106	05/06/99	09/24/02					No apparent change
20-07-02	B-107	12/02/98	05/22/02	04/21/03				No apparent change
20-07-05	B-107	09/25/97	05/23/02					No apparent change
20-07-08	B-107	09/26/97	05/23/02					No apparent change
20-07-11	B-107	09/26/97	05/23/02	04/21/03				No apparent change; possible ^{90}Sr at 72 ft
20-08-02	B-108	12/04/98	09/23/02					No apparent change
20-08-07	B-108	10/29/98	09/19/02					No apparent change
20-12-03	B-109	11/06/98	09/25/02					No apparent change
20-09-06	B-109	09/19/97	09/23/02					No apparent change
20-10-02	B-110	10/27/98	05/30/02	04/08/03				No apparent change; possible ^{90}Sr at 75 ft
20-10-07	B-110	11/24/98	05/29/02	04/08/03				No apparent change
20-10-09	B-110	11/30/98	05/30/02					No apparent change
20-10-12	B-110	10/27/98	09/19/02					No apparent change
20-11-09	B-111	09/02/97	09/25/02					No apparent change
20-12-06	B-111	11/03/98	09/23/02					No apparent change
21-00-05	BX-101	05/28/97	03/14/02	03/26/03				No apparent change
21-01-01	BX-101	05/16/97	03/25/02	03/31/03				No apparent change
21-01-02	BX-101	05/08/97	03/13/02	03/20/03				No apparent change
21-00-02	BX-102	06/10/97	08/13/01	09/04/02	09/30/03			No apparent change
21-02-01	BX-102	05/12/97	09/06/01					No apparent change; Requires medium detector
21-02-03	BX-102	05/12/97	08/14/01	03/13/02	09/04/02	03/20/03	09/23/03	No apparent change
21-02-04	BX-102	05/21/97	09/04/01					No apparent change; HRLS 6/27/02
21-02-06	BX-102	05/16/97	08/15/01	09/04/02	09/25/03			No apparent change
21-02-07	BX-102	05/21/97	08/14/01					No apparent change
21-02-11	BX-102	06/06/97	08/16/01					No apparent change

Table 3-3. Results of the Hanford Tank Farms Vadose Zone Monitoring for WMA B-BX-BY

Borehole Number	Tank	Baseline SGLS Log	RAS Event A	RAS Event B	RAS Event C	RAS Event D	RAS Event E	Comment
21-05-03	BX-102	07/17/97	08/16/01					No apparent change
21-27-01	BX-102	06/17/97	08/28/01	03/13/02	09/04/02	03/20/03	09/29/03	No apparent change
21-27-02	BX-102	06/26/97	08/20/01	09/04/02	09/30/03			No apparent change
21-27-06	BX-102	07/01/97	08/15/01					No apparent change
21-27-07	BX-102	06/26/97	08/15/01	09/04/02	09/29/03			No apparent change
21-27-08	BX-102	06/25/97	08/14/01	03/13/02	09/04/02	03/26/03	09/24/03	Apparent change 137.5-148.5 ft not confirmed
21-27-09	BX-102	07/01/97	08/16/01	09/04/02	09/24/03			No apparent change
21-27-10	BX-102	06/26/97	08/13/01	09/04/02	09/30/03			No apparent change
21-27-11	BX-102	06/18/97	08/20/01	03/14/02	09/04/02	03/21/03	09/25/03	No apparent change
21-03-03	BX-103	05/30/97	08/28/01	02/25/02	09/04/02	03/21/03		No apparent change
21-03-05	BX-103	05/30/97	02/25/02	03/20/03				No apparent change
21-03-07	BX-103	06/06/97	03/14/02					No apparent change
21-03-11	BX-103	06/05/97	02/25/02					No apparent change
21-04-04	BX-104	05/16/97	03/18/02					No apparent change
21-04-06	BX-104	05/23/97	03/18/02					No apparent change
21-04-11	BX-104	05/20/97	03/18/02	03/27/03				No apparent change
21-05-05	BX-105	07/24/97	03/18/02	03/21/03				No apparent change
21-05-06	BX-105	07/24/97	03/19/02	03/27/03				No apparent change
21-06-05	BX-106	06/10/97	03/25/02	04/01/03				No apparent change
21-04-08	BX-107	05/22/97	08/29/01	09/05/02				No apparent change
21-07-03	BX-107	06/24/97	08/29/01	09/05/02				No apparent change
21-07-06	BX-107	06/18/97	09/05/01					No apparent change
21-08-06	BX-107	08/15/97	03/19/02					No apparent change
21-08-05	BX-108	08/01/97	03/19/02					No apparent change
21-08-07	BX-108	08/15/97	03/19/02	03/27/03				No apparent change
21-08-12	BX-109	08/08/97	08/29/01	09/05/02	09/23/03			No apparent change, decrease 50-70 ft ^{60}Co decay
21-12-02	BX-109	07/03/97	08/29/01	09/04/02	09/23/03			Abnormal decrease 40-45 ft.
21-00-07	BX-110	08/01/97	09/23/03					No apparent change
21-10-01	BX-110	08/08/97	08/30/01	09/05/02	09/22/03			No apparent change
21-10-03	BX-110	08/06/97	08/30/01					No apparent change
21-10-05	BX-110	08/05/97	09/06/01	09/08/02				No apparent change; requires HRLS
21-10-07	BX-110	07/31/97	09/19/03					No apparent change
21-10-11	BX-110	07/30/97	09/19/03					No apparent change
21-00-09	BX-111	08/04/97	03/19/02	03/13/03				No apparent change
21-00-21	BX-111	08/06/97	03/20/02	03/13/03				No apparent change
21-00-22	BX-111	08/07/97	03/20/02	03/13/03				No apparent change
21-11-03	BX-111	07/29/97	03/25/02	04/02/03				No apparent change
21-11-04	BX-111	07/28/97	03/21/02	04/02/03				No apparent change
21-11-05	BX-111	07/25/97	03/20/02	03/13/03				No apparent change

Table 3-3. Results of the Hanford Tank Farms Vadose Zone Monitoring for WMA B-BX-BY

Borehole Number	Tank	Baseline SGLS Log	RAS Event A	RAS Event B	RAS Event C	RAS Event D	RAS Event E	Comment
21-11-07	BX-111	07/24/97	03/20/02	03/13/03				No apparent change
22-01-04	BY-101	08/01/95	07/22/02					No apparent change
22-01-07	BY-101	07/26/95	11/25/02					No apparent change
22-00-04	BY-102	08/01/95	07/23/02					No apparent change
22-02-01	BY-102	07/24/95	07/23/02					No apparent change
22-02-09	BY-102	07/24/95	08/20/02					No apparent change
22-00-02	BY-103	08/04/95	11/15/01	07/25/02	04/07/03			No apparent change
22-00-03	BY-103	08/02/95	11/19/01	11/25/02				No apparent change
22-03-04	BY-103	08/07/95	11/15/01	07/23/02	04/07/03			Possible change 77-82 ft not confirmed
22-03-05	BY-103	07/25/95	12/20/01					No apparent change
22-03-06	BY-103	08/09/95	11/16/01	11/15/02				No apparent change
22-03-07	BY-103	08/11/95	11/26/01	11/21/02				No apparent change
22-03-08	BY-103	08/16/95	11/19/01	11/21/02				No apparent change
22-03-09	BY-103	07/27/95	11/26/01	11/21/02				No apparent change
22-04-07	BY-104	08/03/95	08/19/02					No apparent change
22-04-09	BY-104	08/08/95	08/12/02					No apparent change
22-04-11	BY-104	08/09/95	07/01/02					No apparent change
22-05-01	BY-105	07/20/95	11/14/01	11/21/02				No apparent change
22-05-05	BY-105	07/21/95	07/01/02					No apparent change
22-05-09	BY-105	07/20/95	11/14/01	11/25/02				No apparent change
22-06-01	BY-106	08/10/95	11/27/01	11/27/02				No apparent change
22-06-07	BY-106	08/21/95	11/28/01	11/27/02				No apparent change
22-06-05	BY-106	08/11/95	11/27/01	07/26/02	04/07/03			No apparent change
22-06-09	BY-106	08/18/95	12/19/01					No apparent change
22-06-11	BY-106	08/16/95	07/26/02					No apparent change
22-07-01	BY-107	08/17/95	12/06/01	11/20/02				No apparent change
22-07-02	BY-107	08/28/95	11/29/01	07/29/02	04/03/03			Apparent change 98-100 ft not confirmed
22-07-05	BY-107	08/29/95	12/12/01	07/29/02	04/03/03			Apparent change 75-81 ft not confirmed
22-07-07	BY-107	08/31/95	12/12/01	08/20/02	04/03/03			No apparent change
22-07-09	BY-107	09/01/95	12/19/01	12/03/02				No apparent change
22-07-10	BY-107	09/06/95	11/25/02					No apparent change
22-08-01	BY-108	09/05/95	12/14/01	11/20/02				No apparent change
22-08-02	BY-108	09/06/95	12/13/01	07/30/02	04/04/03			No apparent change
22-08-05	BY-108	08/23/95	12/17/01	07/30/02	11/20/02	04/04/03		Apparent change 75-82 ft not confirmed
22-08-06	BY-108	08/23/95	12/14/01	11/19/02				No apparent change
22-08-07	BY-108	08/29/95	12/17/01	11/20/02				No apparent change
22-08-09	BY-108	08/31/95	08/07/02					No apparent change
22-08-12	BY-108	09/01/95	12/13/01	08/19/02	04/04/03			No apparent change
22-09-01	BY-109	09/07/95	11/19/02					No apparent change
22-09-02	BY-109	09/08/95	11/19/02					No apparent change
22-09-05	BY-109	09/12/95	11/19/02					No apparent change

Table 3-3. Results of the Hanford Tank Farms Vadose Zone Monitoring for WMA B-BX-BY

Borehole Number	Tank	Baseline SGLS Log	RAS Event A	RAS Event B	RAS Event C	RAS Event D	RAS Event E	Comment
22-09-07	BY-109	09/13/95	08/07/02					No apparent change
22-09-08	BY-109	09/15/95	08/21/02					No apparent change
22-09-11	BY-109	09/14/95	08/13/02					No apparent change
22-10-05	BY-110	09/13/95	12/11/01	11/19/02				No apparent change
22-10-07	BY-110	09/11/95	12/11/01	07/18/02	04/03/03			No apparent change
22-10-09	BY-110	09/12/95	07/18/02					No apparent change
22-10-10	BY-110	09/09/95	08/13/02					No apparent change
22-11-01	BY-111	09/16/95	08/07/02					No apparent change
22-11-09	BY-111	09/15/95	08/06/02					No apparent change
22-12-03	BY-112	09/17/95	11/18/02					No apparent change
22-12-05	BY-112	09/16/95	11/18/02					No apparent change
22-12-06	BY-112	09/18/95	11/18/02					No apparent change

3.6.1.1 B Tank Farm

DOE (2000a) reported that ^{137}Cs was the major gamma-emitting contaminant detected in the B Tank Farm vadose zone. ^{60}Co, ^{154}Eu, and, to a lesser degree, ^{152}Eu, were also detected in the vadose zone sediments and were often associated with occurrences of ^{137}Cs. In addition, the presence of the beta-emitting radionuclide ^{90}Sr is suspected around several boreholes. The contamination identified resulted from tank leaks, piping leaks, and surface spills, and, most likely, a combination of these events. There was no indication that the ^{137}Cs, ^{60}Co, ^{154}Eu, or potential ^{90}Sr contamination identified in the vadose zone below the B Tank Farm had reached the groundwater at that time. Table 3-4 summarizes the results of the B Tank Farm spectral gamma logging for the Hanford Tank Farms Baseline Characterization Project (DOE 2000a, 2000d, and individual Tank Summary Data Reports).

Table 3-4. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for the B Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for B Tank Farm
B-101 (DOE 1998c)	Anomalous activity was reported at a depth of 55 ft (601 ft elevation) in borehole 20-01-01 (Dukelow 1974a). Anomalous activity was also noted in borehole 20-01-07 in April 1975. The activity in borehole 20-01-01 continued to increase as well (Jensen 1975a). In July 1975, a third occurrence report documented anomalous activity at the same general depth in boreholes 20-01-05 and 20-01-06 (Jensen 1975b). The SGLS detected ^{137}Cs and ^{60}Co between 40 and 60 ft log depth (~617 and ~597 ft elevation) in boreholes 20-01-01, 20-01-06, and 20-00-05. In addition, anomalous activity was noted within this depth interval on the historical gross gamma logs for borehole 20-01-05. The contamination detected from 40 to 60 ft log depth (618 and 598 ft elevation) in borehole 20-00-05 is probably continuous and correlatable with the contamination along the same interval in borehole 20-01-06. The plume has probably migrated at least as far south as borehole 20-00-05.
B-102 (DOE 1999b)	No evidence of vadose zone contamination.

Table 3-4. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for the B Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for B Tank Farm
B-103 (DOE 1998d)	Liquid-level decreases in tank B-103 before 1975 were attributed to moisture removed from the tank via an exhauster. However, the tank was designated an assumed leaker in 1978 because of anomalous activity detected near the base of the tank farm excavation at boreholes 20-03-03 and 20-03-06. Historical gross gamma-ray logs indicate that the anomalous activity was present as early as 1972. However, no significant subsurface contamination was detected by the SGLS, suggesting that any contamination that resulted from the leak consisted of short-lived radionuclides that have since decayed away.
B-104 (DOE 1999c)	SGLS data and available information from other sources do not identify any active leaks from this tank. However, the data indicate that surface spills and a possible leak from a nearby pipeline or transfer line may have occurred in the past. In addition, contaminant plumes have been intercepted by boreholes located on the north and west sides of tank B-104. The plumes are believed to have originated from leaks from tanks B-105 and B-107.
B-105 (DOE 1999d)	^{137}Cs contamination detected from 46 to 52.5 ft log depth (612 to 605.5 ft elevation) in boreholes 20-05-06 and 20-06-06 probably originated from a leak at tank B-105. Tank B-105 was declared inactive and designated an assumed leaker in 1978.
B-106 (DOE 1999e)	Boreholes 20-05-06 and 20-06-06 are approximately 100 ft apart and on opposite sides of tank B-105. Both exhibit significant ^{137}Cs at the same general depths between 46 and 57 ft log depth (612 and 601 ft elevation), about 7 to 10 ft below the tank bottoms. If the source were a leak from tank B-105, the contamination most likely would have spread laterally along the base of the excavation and intersected boreholes 20-02-09 and 20-08-03 as well as 20-06-06. In addition, the contamination detected in borehole 20-06-06 is more extensive and higher in concentration than contamination detected in borehole 20-05-06, which may suggest this borehole is closer to the source; borehole 20-06-06 is located approximately 5.5 ft from tank B-106 and about 17.5 ft from tank B-105. Therefore, available data suggest contamination detected in borehole 20-05-06 most likely originated from a leak in the south side of tank B-105, and the contamination detected in borehole 20-06-06 may have originated from a leak in the south side of tank B-106. A cascade line leak is also a possibility for either or both contamination plumes.
B-107 (DOE 1999f)	^{137}Cs, ^{60}Co, ^{154}Eu, and ^{152}Eu were detected between 35 and 60 ft log depth (623 and 598 ft elevation) at borehole 20-07-02. The contamination probably originated from a leak from tank B-107 prior to 1970. A second plume consisting of short-lived radionuclides was encountered between 60 and 80 ft when borehole 20-07-05 log depth (598 and 578 ft elevation) was drilled southeast of the tank in 1970.
B-108 (DOE 1999g)	SGLS data and historical information do not provide evidence of a leak from tank B-108. Anomalous total gamma was encountered in borehole 20-08-07, which is probably ^{90}Sr that originated from tank B-110.
B-109 (DOE 1999h)	Boreholes south and west of tank B-109 indicate the presence of ^{60}Co below the base of the tank starting at log depths of about 68 and 73 ft (588 and 583 ft elevation), respectively. The ^{60}Co detected in borehole 20-12-03 was identified when the borehole was drilled in 1972. The predominant constituent appears to have been ^{106}Ru, on the basis of the observed decay rate in the historical gross gamma data. This plume is believed to have originated from tank B-112.
B-110 (DOE 1999i)	Tank B-110 was recognized as a suspected leaker in 1973 (Brevick et al. 1994) as the result of a liquid-level decrease (Welty 1988). In July 1974, an increase in radiation levels was observed in borehole 20-10-07 at a log depth of 47 ft (612 ft elevation). A zone of extremely high gamma radiation was encountered from 25.5 to 100 ft log depth (633.7 to 559.2 ft elevation) at borehole 20-10-12, suggesting a possible leak from a tank inlet or cascade line near the 25-ft depth. The location and magnitude of contamination indicate that it likely originated from a cascade line leak near tank B-110 and possibly a leak from tank B-110 itself. The drilling log and historical gross gamma logs indicate that borehole 20-10-12 penetrated preexisting contamination, suggesting that ^{137}Cs, ^{154}Eu, and ^{90}Sr migrated as a plume from the leak source through the vadose zone. Probable ^{90}Sr contamination has been identified in boreholes at least 80 ft away in a northeasterly direction.

Table 3-4. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for the B Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for B Tank Farm
B-111 (DOE 1999j)	Tank B-111 was categorized as questionable integrity in 1978, on the basis of activity observed in the first gross gamma-ray log data from boreholes 20-11-09 and 20-12-06 in 1973 (Welty and Vermeulen 1988). This gamma activity was attributed to an unexplained liquid-level decrease of 3.1 in. between March 1972 and June 1973; equivalent to a loss of 8,525 gal (Welty and Vermeulen 1988; Welty 1988). The small zone of ^{137}Cs from 36 to 37.5 ft log depth (621.5 to 620 ft elevation) in borehole 20-11-09 may have resulted from a leak from a transfer line or tank B-111. The zone of anomalous activity detected between 41 and 48 ft log depth (616 and 609 ft elevation) in borehole 20-12-06 may represent radionuclides not identified by the SGLS, which suggests the presence of ^{90}Sr. However, the rate of decrease in historical gamma activity indicates a consistently elevated background level in this region. Historical gamma activity also indicates that the contaminant plume originally consisted of short-lived radionuclides (including ^{106}Ru) as early as January 1973 but had mostly decayed away by late 1978.
B-112 (DOE 1999k)	Drilling logs and historical gross gamma data suggest that a broad contaminant plume existed east and south of tank B-112 during the early 1970s. The rapid rate of decline in historical gross gamma data indicates the contamination was predominantly a short-lived radionuclide such as ^{106}Ru. Small amounts of ^{60}Co were detected by the SGLS in this region.
B-201	There are few boreholes near these tanks. Tank Summary Data Reports were not prepared for these tanks.
B-202	
B-203	
B-204	

DOE (2000a) reported a small ^{137}Cs and ^{154}Eu plume around one borehole near the south side of tank B-101, an assumed leaker. Regions of ^{137}Cs and ^{60}Co contamination were also detected deeper in the vadose zone around boreholes located near the northeast and south sides of the tank. This contamination is believed to have originated from a leak from tank B-101 near the maximum operating level of the tank.

DOE (2000a) reported an interval of deep, low-intensity ^{60}Co contamination around one borehole near the west side of tank B-102. The contamination appears to have migrated from a distant leak source such as tank B-105 to the west, or tank B-103 to the north, both of which are known leakers.

Regions of highly concentrated ^{137}Cs contamination were detected around single boreholes located near the north and south sides of tank B-105 (an assumed leaker). Available data suggest that the contamination detected in these boreholes probably originated from tank B-105, but from separate leak events that occurred in the vicinity of each borehole (DOE 2000a).

A large plume of ^{137}Cs, ^{60}Co, and ^{154}Eu contamination identified around one borehole located near the northeast side of tank B-107 is probably directly attributable to a leak from tank B-107 (DOE 2000a). A deeper plume of ^{137}Cs contamination detected around this borehole probably also originated from a leak from tank B-107 and migrated to this region through the Hanford formation sediments.

A discrete zone of ^{137}Cs and ^{154}Eu contamination was detected around one borehole located near a cluster of inlet pipes connected to the southwest side of tank B-110 (DOE 2000a). Available data suggest that this contamination may consist of residual waste contained within the inlet piping.

An extensive region of highly concentrated ^{137}Cs contamination was detected around one borehole located near the north side of tank B-110 (DOE 2000a). This contamination likely originated from a leak from the B-110 to B-111 cascade line or from tank B-110 itself. The location and potential magnitude of the ^{137}Cs contamination within this region of the vadose zone indicate that this borehole is very close to the leak source. The plume appears to consist primarily of ^{137}Cs, but probably also contains ^{90}Sr and lesser amounts of ^{60}Co and ^{154}Eu; ruthenium-106 (^{106}Ru) that has since decayed away is also believed to have been an original constituent of this plume. Suspected ^{90}Sr contamination has been identified at the same depth intervals around boreholes located approximately 40 ft southeast and 80 ft northeast of the leak source, suggesting the presence of a relatively extensive contaminant plume.

For the B-BX-BY Field Investigation Report (Knepp 2002), a new borehole (299-E33-46) was drilled to groundwater. Borehole 299-E33-46 (Figure 2) was installed northeast of tank B-110 through a suspected ^{90}Sr vadose zone plume where ^{90}Sr was detected down to 85 ft (26 m) bgs (572 ft elevation) with activities up to 11,250 pCi/g. Other tank wastes contaminants (e.g., nitrate and ^{99}Tc) were detected as deep as 200 ft (69 m) bgs (457 ft elevation). The major conclusion of the B-BX-BY Field Investigation Report (Knepp 2002) is that: "*The future impacts from wastes currently in the vadose zone that resulted from past releases from the B, BX, or BY tank farms are not expected to exceed drinking water standards as long as high volume liquid discharges to the vadose zone are eliminated.*"

3.6.1.2 BX Tank Farm

The majority of the contamination was detected in the eastern portion of the BX Tank Farm, where ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu were detected throughout the 150-ft depths (~510 ft elevation) of several of the boreholes in this area (DOE 1998a). This contamination is related to leakage from tanks BX-101 and BX-102, which are currently designated leakers. Wastes that have leaked from these tanks created complex contaminant plumes. Most of the monitoring boreholes surrounding tanks BX-101 and BX-102 are only 100 ft deep (~560 ft elevation); therefore, the presence and westward extent of these contaminant plumes could not be evaluated. Table 3-5 summarizes the results of the spectral gamma logging for the Hanford Tank Farms Baseline Characterization Project (DOE 1998a, 2000b, and individual Tank Summary Data Reports).

Table 3-5. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm
BX-101 (DOE 1998e)	Anomalous gamma activity recorded in borehole 21-01-01 in October 1974 and in boreholes 21-01-07 and 21-01-05 a short time later indicated a possible leak from tank BX-101 (Dukelow 1974b). The SGLS and historical gross gamma log data indicate that tank contents have leaked from the south side of tank BX-101.

Table 3-5. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm
BX-102 (DOE 1997b)	The first documented leak from tank BX-102 was through a spare inlet in 1951, and elevated gamma activity was detected at borehole 21-27-11 a few weeks later (GE 1951). In late 1969, contaminants again reached borehole 21-27-11 (about 72 ft from the tank). This was the only borehole in the area at that time. According to Womack and Larkin (1971), the late-1969 event was the second contaminant plume to reach the borehole. Elevated activity was apparently detected around this borehole in late 1959; the activity steadily decreased through late 1969. Boreholes 21-02-01, 21-02-03, 21-02-04, 21-02-06, 21-02-07, 21-02-11, 21-01-01, 21-01-02, 21-27-01, 21-27-02, 21-27-06, 21-27-07, 21-27-08, 21-27-09, 21-27-10, and 21-00-02 were drilled in 1970 to characterize the leak from tank BX-102 (Womack and Larkin 1971). This 1970 investigation concluded that the source of the contamination was probably a leak from tank BX-102, on the southeast side near the tank footing, approximately 40 ft bgs (~616 ft elevation). It was also suggested that contamination was present in the vadose zone around borehole 21-27-11 long before the tank was suspected of leaking. This first contamination is speculated to have resulted from a cascade line leak between tanks BX-102 and BX-103 in 1951 (General Electric 1951). SGLS data do not support this leak scenario; little to no contamination was detected in boreholes 21-02-11 and 21-02-01. These boreholes are located adjacent to the cascade line and would have intercepted any contamination originating from such a leak. Sediment samples were acquired as borehole 21-02-04 was constructed; the samples were apparently only analyzed for ^{137}Cs. The data show ^{137}Cs in the groundwater at about 255 ft (404 ft elevation). Womack and Larkin (1971) suggested this contamination was carried down during the drilling operations. Anomalous activity was noted in the driller's log from 198 to 200 ft, 207 to 208 ft, at 214 ft, 216 ft, 240 ft, from 246 to 248 ft, and at 254 ft (461 to 459 ft, 452 to 451 ft, at 445 ft, 443 ft, 419 ft, from 413 to 411 ft, and at 405 ft elevations). With the exception of the sample at 254 ft (405 ft elevation), this activity was not evaluated in the 1970 investigation. When borehole 21-02-04 (299-E33-27, Figure 2) was logged with the SGLS, the system was saturated throughout most of the logged interval. Historical gross gamma data from as early as 1975 indicate contamination was present from the ground surface to at least 150 ft (the maximum depth of the gross gamma logging) or 509 ft elevation. The contamination detected with both the SGLS and the gross gamma logs is probably much more extensive than the relatively narrow zone identified during the 1970 investigation. Because only ^{137}Cs data above 10,000 pCi/g were presented, contamination was likely present but not reported. The SGLS data do not favorably compare to the data presented in the 1970 tank leak investigation. Womack and Larkin (1971) presented ^{137}Cs data for borehole 21-02-04 at only a few small intervals. Apparently, not all of the detected contamination was analyzed, most notably, contamination that was detected below a log depth of 200 ft (459 ft elevation). Historical gross gamma log data for borehole 21-02-04 acquired 5 years later clearly show anomalous activity from the ground surface to the bottom of the log at 150 ft (5099 ft elevation). SGLS data show extensive contamination from the ground surface to 231 ft (total depth of the borehole) or 428 ft elevation.
BX-103 (DOE 1998f)	No evidence of significant vadose contamination at depth that would indicate a tank leak.
BX-104 (DOE 1998g)	The numerous zones of ^{60}Co detected from 65 to 100 ft (~595 to ~560 ft elevation) in boreholes 21-04-08, 21-07-03, 21-04-11, and 21-05-06 appear to be remnants of a vadose plume that could have originated from a leak from any of the tanks in the vicinity, including tank BX-104.

Table 3-5. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm
BX-105 (DOE 1998h)	The zones of ^{60}Co contamination detected between 70 and 90 ft log depth (589 and 569 ft elevation) in boreholes 21-05-05 and 21-05-06 appear to be remnants of a plume that probably originated from nearby tanks assumed to have leaked, such as tanks BX-101 or BX-102. The low amount of activity indicates that the contamination probably migrated a considerable distance downward and laterally through the vadose zone. The isolated ^{60}Co detected at about 70 ft (589 ft elevation) in each borehole indicates that some of the contamination may have accumulated within a laterally extensive layer of fine-grained sediments. The data obtained using the SGLS and the geologic and historical information available from other sources do not identify any active leaks from tank BX-105.
BX-106 (DOE 1998i)	^{137}Cs, ^{125}Sb, and processed uranium (^{235}U and ^{238}U) detected between 35 and 55 ft log depth (623 and 603 ft elevation) in borehole 21-06-05 most likely resulted from a leak from tank BX-106. The highest concentrations of ^{137}Cs occur at about 39 ft (619 ft elevation). ^{125}Sb and $^{235/238}$U detected between 41 and 54 ft log depth (617 and 604 ft elevation) appear to be associated with the overlying ^{137}Cs and appear to have migrated below the tank farm excavation into the undisturbed sediments of the Hanford formation. The contamination distribution is not continuous in the upper portion of the borehole; therefore, it is unlikely that the plume originated from surface contamination that migrated down the side of the tank. In addition, the radionuclides have segregated below the base of the tank in a pattern that would be expected of a nearby concentrated source, and no contamination was identified in any of the boreholes between borehole 21-06-05 and adjacent tanks. On the basis of this information, it is concluded that the contamination originated from a leak from tank BX-106. No other source appears plausible. Because uranium was identified as a principal component in the plume it is likely that the tank leaked in the early years between when the tank was first constructed and the mid-1950s when the uranium-laden waste was removed from the tank.
BX-107 (DOE 1998j)	SGLS data and geologic and historical information indicate that contamination around this tank resulted from surface spills and pipeline and/or tank leaks. Welty (1988) identified a transfer line leak as the source of widespread contamination in boreholes 21-07-06 and 21-10-03. A review of historical gross gamma-ray logs indicates that plumes existed from about 66 to 68 ft (594 to 592 ft elevation) and 85 ft (575 ft elevation) to the bottom of borehole 21-07-03 (560 ft elevation), from about 60 to 65 ft (600 to 595 ft elevation) and 84 ft (576 ft elevation) to the bottom of borehole 21-04-08 (560 ft elevation), and from 44 to 51 ft (615 to 608 ft elevation) and 63 to 67 ft (596 to 592 ft elevation) in borehole 21-08-06. ^{60}Co contamination in these boreholes probably represents remnants of these plumes, which have mostly decayed away. The total vertical extent of this contamination could not be determined.
BX-108 (DOE 1998k)	Gross gamma activity increased in borehole 21-08-06 as noted in Welty (1988).
BX-109 (DOE 1998l)	SGLS data and historical information indicate a subsurface contaminant plume exists in the vicinity of this tank around borehole 21-08-12. This contamination may be related to tank BX-109, but it is more likely associated with tank BX-108. A very small plume was detected at the base of the tank around borehole 21-12-02. The source of this contamination is unknown, but it could be from tank BX-112 or BX-109. The zone of slightly elevated ^{137}Cs contamination detected between 21.5 and 24 ft (635.8 and 633.3 ft elevation) around borehole 21-09-12 may be the result of a subsurface leak from the overflow outlet located on the north side of tank BX-109.
BX-110 (DOE 1998m)	The SGLS detected contamination from 8 to 65 ft in boreholes 21-10-01, 21-10-03, and 21-10-05. This contamination suggests a leak from tank BX-110, the associated service piping, or both. This contamination is most prominent in borehole 21-10-03 and extends from 8 to 65 ft (652 to 595 ft elevation). Similar contamination occurs from 36 to 62 ft (624 to 598 ft elevation) in borehole 21-10-05 and from 38 to 42 ft (622 to 618 ft elevation) in borehole 21-10-01. Historical gross gamma records show that this contamination was present before 1972.

Table 3-5. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BX Tank Farm
BX-111 (DOE 1998n)	In 1976, tank BX-111 was categorized as "questionable integrity" because of gross gamma activity increases at about 40 ft (~619 ft elevation) in boreholes 21-11-03, 21-11-04, 21-11-05, and 21-11-07 (Walker 1988).
BX-112 (DOE 1998o)	The SGLS data and historical information do not identify any apparent leaks from tank BX-112.

An investigation of the leak at tank BX-102 was initiated in 1970 (Womack and Larkin 1971). In 1970, the gamma-ray activity in borehole 21-27-11 (299-E33-61, Figure 2) increased. Although this borehole is located 72 ft to the east, tank BX-102 was suspected to be the source of the activity. Part of the investigation involved installing 19 new boreholes in an attempt to determine the lateral and vertical extents of the contamination. Various geophysical logging tools, including neutron-moisture probes, scintillation gamma-ray probes, and Geiger-Mueller detectors, were used to collect information for the investigation; the logging results are provided in Womack and Larkin (1971). The data indicated a correlation between elevated peaks on the neutron-moisture logs with zones of high gamma-ray activity.

As part of the Womack and Larkin (1971) investigation, borehole 21-02-04 (299-E33-27, Figure 2) was drilled to groundwater on the south side of tank BX-102. ^{137}Cs contamination was detected in groundwater samples acquired in this borehole. Additional sampling and analyses indicated the ^{137}Cs concentrations in the groundwater beneath the BX Tank Farm were higher than the concentrations from groundwater beneath the cribs. Womack and Larkin (1971) concluded that the ^{137}Cs contamination in the groundwater beneath the BX Tank Farm was due to the spread of contamination during the drilling of borehole 21-02-04 (299-E33-27). As discussed in Table 3-5, the SGLS data for borehole 21-02-04 (299-E33-27) do not favorably compare to the data presented in Womack and Larkin (1971).

The B-BX-BY Field Investigation Report (Knepp 2002) focused on the area east of tank BX-102. This area was investigated by drilling a new borehole to groundwater and evaluating existing borehole data, including groundwater and geophysical data. Borehole 299-E33-45 (Figure 2) was installed about 70 ft (23 m) east of tank BX-102 to investigate a man-made uranium plume in the vadose zone. In borehole 299-E33-45, ^{99}Tc was detected in porewater extracted from samples collected from 120 to 170 ft (36 to 52 m) bgs (538 to 488 ft elevation). Measured ^{99}Tc values ranged up to 546,000 pCi/L. Uranium was detected at 70 to 170 ft (21 to 52 m) bgs (588 to 488 ft elevation) with the highest concentration at approximately 130 ft (40 m) bgs (528 ft elevation). Mobile contaminants (e.g., nitrates and cations) have a similar spatial profile to ^{99}Tc, with retarded contaminants (i.e., most metals) having a distribution similar to uranium. In addition, kriging estimates of uranium inventory and distribution were completed using spectral gamma and soil concentration data (Figure 15). It was determined that the peak measured concentrations in groundwater at well 299-E33-41 (Figure 2), which lies directly east of BX Tank Farm, are most likely due to releases from BX Tank Farm. Similarly, the processed uranium in the vadose zone detected at 299-E33-41 was considered part of the processed uranium vadose zone plume extending out of the BX Tank Farm (Pruess and Yabusaki in Knepp 2002 and Wood et al. 2000b). "*Lateral migration of uranium-238 from the BX tank farm extends beyond the dry wells to at least 299-E33-41, a RCRA well an additional 100 ft (30.48 m) to the northeast of the contemporary BX-102 borehole (i.e., 299-E33-45), indicating lateral migration of at least 170 ft (51.82 m) at a vertical depth of 137 ft (41.76 m)* [521 ft elevation]*"* (Pruess and Yabusaki in Knepp 2002).

The estimated migration of the uranium plume associated with tank BX-102 is approximately 2 m per year after the initial surge and appears generally consistent with subsurface flow along small scale, silty fine sand layers at depths of about 75, 100, and 120 ft (583, 558, and 538 ft elevation), which dip about 1.5 to 2 degrees to the northeast (Pruess and Yabusaki in Knepp 2002). "*Modeling results suggest that the few (2 or 3) semi-continuous silty fine sand layers that have been identified in the H2 unit cannot by themselves account for current moisture contents and radionuclide distributions to the east and northeast of BX-102"* (Pruess and Yabusaki in Knepp 2002). Pruess and Yabusaki in (Knepp 2002) report that: "*The current interpretation, based on observations at the field experiments, is that there are numerous, discontinuous, low permeability laminations/lenses in the H2 unit oriented with 3% general slope towards the northeast. Liquid migrates sub-horizontally along a lamination until the lamination terminates or is weak enough to allow breakthrough, whereupon it migrates vertically until encountering another lamination.*" "*The driving force for moisture redistribution of the 91,600-gal pulse in 1951 is significantly diminished within a few weeks of the end of the release, whereupon recharge becomes the principal driving force. For a 10 cm/year recharge with 5% moisture content, the nominal pore velocity and transport rate is 2 meters per year"* (Pruess and Yabusaki in Knepp 2002).

In 1997, 16 groundwater monitoring wells and vadose zone boreholes were logged in support of a RCRA groundwater assessment of the B-BX-BY WMA (Price 1998; PNNL 1999). These 16 spectral gamma-ray logs were adjacent to the B-BX-BY WMA near the inactive liquid disposal facilities. *"Two wells (299-E33-18 and -41) showed migration of uranium-235 and uranium-238. In well 299-E33-18, the uranium-238 activity changed from "not detected" in September 1992 to 400 pCi/g when logged in September 1997. Uranium movement occurred above the water table between 70.7* (232 ft log depth, 423 ft elevation) *and 75.9 m* (249 ft log depth, 406 ft elevation). *The water table is at 76.5 m* (251 ft log depth, 404 ft elevation) *in this well. Results from groundwater samples from this well indicate rising uranium activities, possibly beginning in 1993 and extending to 1997"* (PNNL 1999). "*In well 299-E33-41, uranium-238 appears to have increased from 200 to 1,000 pCi/g between 1991 (when the well was installed) and September 1997 in a deep zone between 67.1* (220.1 ft log depth, 438 ft elevation) *and 73.2 m* (240.2 ft log depth, 418 ft elevation). *Also, comparison of the current and past logs suggests that the peak activity and the entire plume of uranium have migrated 1.2* (3.9 ft) *to 6.1 m* (20 ft) *deeper into the soil column. However, the well casing and seal were changed between the two logging events, complicating the comparison of data"* (PNNL 1999).

DOE (1998a) reported high ^{137}Cs concentrations in borehole 21-07-06. This borehole is located on the south side of tank BX-107, which is designated as a sound tank. No specific information is available that could be used to attribute the contamination detected in borehole 21-07-06 to a pipeline leak as documented in Welty (1988).

Several waste disposal facilities adjacent to the BX Tank Farm were investigated during the preparation of the BX Tank Farm Report (DOE 1998a) to evaluate the potential influence that wastes disposed at these facilities may have had on the distribution of contamination at the BX Tank Farm. DOE (1998a) concluded that there is no indication that wastes discharged to the nearby facilities are related to contamination detected in the vadose zone beneath the tanks.

3.6.1.3 BY Tank Farm

The spectral gamma log data show ^{137}Cs is the most abundant and highest concentration radionuclide detected throughout the BY Tank Farm (DOE 1997a). ^{60}Co was also detected in fairly extensive

distributions, but in much lower concentrations than ^{137}Cs; ^{60}Co was often detected at the bottoms of boreholes. Other gamma-emitting radionuclides detected are ^{125}Sb and ^{154}Eu. Table 3-6 summarizes the results of the spectral gamma logging for the Hanford Tank Farms Baseline Characterization Project (DOE 1997a and 2000c and individual Tank Summary Data Reports).

Table 3-6. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BY Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BY Tank Farm
BY-101 (DOE 1996a)	No conclusive evidence was derived from the SGLS data to indicate that the tank has leaked. However, zones of elevated ^{137}Cs and ^{60}Co occur in the operation depth range of the tank.
BY-102 (DOE 1996b)	Contamination profiles in boreholes around tank BY-102 suggest the possibility of more than one subsurface plume. The contamination from 44 to 52 ft log depth (609 to 601 ft) in borehole 22-02-01 likely originated from tank BY-102. However, the possibility that the contamination in this borehole originated from tank BY-103 cannot be discounted. A 1971 gross gamma log in borehole 22-02-09 (Dukelow 1980) showed contamination between 35 and 55 ft log depth (618 and 598 ft elevation).
BY-103 (DOE 1996c)	Tank BY-103 was classified as a "borderline leaker" in 1970 based on anomalous activity in borehole 22-00-03 that appeared in 1969. In 1971, high count rates also occurred in borehole 22-03-05. The operating level was lowered to 13 ft. In 1972 and 1973, the zone of high count rates in borehole 22-03-09 widened from 56 to 77 ft log depth (596 to 575 ft elevation). Logging of new boreholes 22-03-04 and 22-03-06 in 1973 showed elevated activity (Borsheim 1973), and tank BY-103 was classified as a confirmed leaker. An increase in activity at 32 ft and changing radiation profile in borehole 22-03-09 prompted an occurrence report (ARCHO 1974) that concluded the tank may have leaked in early 1974, but that it probably no longer was leaking after the liquid level was lowered. The high radiation profile in borehole 22-03-05 indicates the leak was probably near this borehole.
BY-104 (DOE 1996d)	No evidence was derived from the SGLS logging data to indicate leakage.
BY-105 (DOE 1996e)	An increase in activity was observed at 67 ft in borehole 22-05-09 (Dukelow 1974c). The source of the radiation increase was believed to be the result of "lateral migration of existing contamination in the soil." The waste level was at about 20 ft above the bottom of the tank, or about 28 ft from ground level (625 ft elevation). Tank BY-105 was categorized as an assumed leaker based on increased gross gamma activity in borehole 22-05-09, which is now believed to be ^{60}Co. However, ^{137}Cs and ^{60}Co contamination measured in borehole 22-05-09 below 60 ft log depth (593 ft elevation) appears to have originated from a subsurface source.
BY-106 (DOE 1996f)	Elevated radiation levels are present at several of the boreholes around tank BY-106. Borehole 22-06-07 has the highest ^{137}Cs concentrations (about 10 pCi/g). The location of the ^{137}Cs contamination at borehole 22-06-07 appears to be controlled mainly by the perforated interval that extends from 40 to 100 ft log depth (613 to 553 ft elevation). Some ^{137}Cs contamination extends below the perforations to total depth at 131 ft (522 ft elevation). The leak in tank BY-106 probably occurred close to borehole 22-06-05, because the contamination was most concentrated in that borehole. The major contaminant present near borehole 22-06-05 is ^{60}Co, rather than ^{137}Cs. Tank Farms gross gamma-ray logs show that the contamination interval at borehole 22-06-05 has been moving downward. The ^{60}Co distribution for borehole 22-03-09 is similar to that for borehole 22-06-05, although the concentration is less and shifted to slightly deeper depths. The concentration of ^{60}Co in borehole 22-06-07 is less than that in boreholes 22-06-05 and 22-03-09, but the thickness of its interval is about the same.

Table 3-6. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BY Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BY Tank Farm
BY-107 (DOE 1996g)	In April 1974, an increase in gamma activity was detected in borehole 22-07-02 at a depth of 29 ft. The gamma activity in four boreholes surrounding tank BY-107 increased. The radiation increases were attributed to migration of old contamination (Dukelow 1975). Jensen (1975c) reported increases in radiation intensities in boreholes 22-07-02 and 22-07-05. Neutron-neutron measurements indicated an unusually high amount of moisture in sediments on the east side of tank BY-107. Several of the boreholes (22-07-02, 22-07-05, 22-07-09, and 22-07-10) have intervals of ^{137}Cs that begin at about 23 ft (~630 ft elevation). The most extensive ^{137}Cs was detected in borehole 22-07-09, where the concentration was almost 4,000 pCi/g. ^{60}Co was detected in boreholes 22-07-01, 22-07-02, 22-07-05, 22-07-07, and 22-07-09. This ^{60}Co probably originated from leakage from tank BY-107. The vertical extent of the ^{60}Co plume is not known, because it extends to total depth in some boreholes.
BY-108 (DOE 1996h)	The profile of the contamination measured in boreholes around tank BY-108 suggests this tank has leaked in the past. Significant amounts of ^{137}Cs contamination were detected below the bottom of the tank in boreholes 22-08-07 and 22-08-09. Possible indications of contamination originating from the tank are shown by elevated ^{137}Cs in boreholes 22-08-06 and 22-08-02 at about 23 to 26 ft in depth (~630 ft elevation). This depth range corresponds with the depth of the top of the tank liner and ancillary piping where fluids may have spilled. Historical gross gamma logs indicate elevated activity in varying amounts in all boreholes associated with tank BY-108. This activity has decreased in intensity with time and generally corresponds with intervals identified as ^{60}Co by the SGLS. The ^{60}Co contamination is typically located at and below depths corresponding to the historical tank waste level.
BY-109 (DOE 1996i)	The high ^{137}Cs concentration near a depth of 24 ft in borehole 22-09-08 indicates that the ancillary piping for tank BY-109, or possibly tank BY-109 itself, has leaked. The ^{60}Co present below about 22 ft log depth (~630 ft elevation) in boreholes 22-09-07, 22-09-08, and 22-09-11 on the west side of tank BY-109 most likely originated from tank BY-109 or its ancillary piping.
BY-110 (DOE 1996j)	^{60}Co was detected in boreholes 22-11-05, 22-07-09, 22-10-05, 22-10-07, and 22-10-10. In boreholes 22-10-05 and 22-10-07, the ^{60}Co contamination was detected at a log depth of 48 ft (605 ft elevation), approximately 3 ft below the bottom of the tank. In boreholes 22-07-09 and 22-10-10, the ^{60}Co contamination was detected deeper in the vadose zone at log depths of 67 and 65 ft (587 and 588 ft elevation), respectively. These ^{60}Co contamination zones may have resulted from deeper migration of contamination from leakage from tanks BY-107 (borehole 22-07-09) and BY-110 (borehole 22-10-10). Tank Farms gross gamma-ray log data for boreholes 22-10-05, 22-10-07, and 22-10-10 suggest vertical migration of contamination. The ^{60}Co contamination in boreholes 22-10-05 and 22-10-07 appears to originate slightly below the base of tank BY-110. ^{60}Co contamination detected in boreholes 22-10-05 and 22-10-07 appears to have originated from leakage from tank BY-110 because the contamination in these two boreholes occurs immediately below the base of the tank. This contamination is unlikely to be related to the leakage from adjacent tank BY-107 because the contamination detected in boreholes surrounding tank BY-107 that are closest to tank BY-110 was located deeper in the vadose zone. The elevation difference can be observed by comparing the ^{60}Co profiles in boreholes 22-07-09 and 22-10-05. The vertical extent of the ^{60}Co is not known, because the plume extends below the bottom of borehole 22-07-09 and may extend below the bottom of borehole 22-10-05.
BY-111 (DOE 1996k)	The profile of the contamination measured in boreholes around tank BY-111 shows near-surface (above 10 ft) contamination spills from ancillary piping. ^{60}Co and ^{137}Cs were detected in borehole 22-11-09. Evidence of processed uranium was detected in borehole 22-11-08 (299-E33-256, Figure 2) at about 62 ft log depth (591 ft elevation). In 1977, OR 77-178 (Garbrick 1977) stated that the vadose zone monitoring boreholes around tank BY-111 "have long shown radiation peaks significantly above background levels."

Table 3-6. Summary of the Hanford Tank Farm Baseline Characterization Project's Results for BY Tank Farm

Tank	Hanford Tank Farm Baseline Characterization Project's Results for BY Tank Farm
BY-112 (DOE 1996l)	SGLS logs show no evidence of a leak from tank BY-112. The ^{137}Cs concentration near 24 ft log depth (628 ft elevation) in borehole 22-12-03 probably originated from tank BY-109 or its piping, where ^{137}Cs was detected at a concentration of about 1,000 pCi/g in borehole 22-09-08 near 24 ft log depth (628 ft elevation). ^{137}Cs concentrations near 28 ft log depth (625 ft elevation) in borehole 22-12-05 also possibly originated from tank BY-109 or its piping. The ^{60}Co contamination, observed in boreholes on the east and south side of tank BY-112, probably migrated from a leak of tank BY-109. Only the boreholes on the east and south sides of tank BY-112 had measurable concentrations of ^{60}Co. The highest ^{60}Co concentration was detected in borehole 22-12-03, apparently in a pipeline near the ground surface. ^{60}Co contamination was also detected from about 84 to 98 ft log depth (568 to 554 ft elevation) in that borehole. Small amounts of ^{60}Co contamination were also detected in boreholes 22-12-01, 22-12-05, and 22-12-06. The source of the ^{60}Co is probably tank BY-109. More ^{60}Co contamination was detected in the boreholes on the west side of tank BY-109 compared to boreholes near tank BY-112.

The highest ^{137}Cs concentrations in the BY Tank Farm boreholes were detected on the southeast side of tank BY-103, supporting the designation of this tank as an assumed leaker (DOE 1997a). Both ^{137}Cs and ^{60}Co were detected in borehole 22-03-05 below a zone of ^{137}Cs contamination with concentrations high enough to saturate the detector. Several other high ^{137}Cs concentrations were detected in the BY Tank Farm boreholes; however, these concentrations were associated with near-surface contamination resulting from surface spills, pipe leaks, or the proximity of the boreholes to pipes containing contamination. ^{137}Cs contamination was detected throughout the lengths of several boreholes, but the concentrations were usually 1 pCi/g and less.

^{60}Co contamination was detected around all the tanks in the BY Tank Farm that are known to have leaked (DOE 1997a). Concentrations were usually less than 10 pCi/g; however, the vertical distributions were extensive. ^{60}Co contamination was often detected above the bases of the tanks and near the ground surface. This contamination was often associated with zones of elevated ^{137}Cs contamination near the ground surface, indicating sources from spills or leaks or proximity of the boreholes to contaminated pipelines.

^{60}Co contamination was often detected alone below the base of the tank farm excavation within fine-grained sediments of the Hanford formation, and the visualizations show extensive ^{60}Co contamination relative to the ^{137}Cs contamination (DOE 1997a). This wide distribution is most likely indicative of the relatively higher mobility of ^{60}Co that may be enhanced by its chemical combination within the constituents of the tank waste.

The presence of ^{60}Co contamination plumes beneath the southern portion of tank BY-110 raises question as to the integrity of this tank (DOE 1997a). Historical documentation reveals evidence of potential for leakage (tar rings and unexplained liquid-level decreases); however, neither this information nor the recent characterization data confirm leakage.

^{60}Co contamination on the west side of tank BY-111 strongly indicates that this tank has leaked in the past (DOE 1997a). Historical documentation records liquid-level decreases coincident with increases in gamma-ray intensities in monitoring boreholes around the west side of this tank. Therefore, on the basis of these data, it was recommended that this tank be reclassified as a leaker.

A majority of the monitoring boreholes in the BY Tank Farm extend only to a depth of about 100 ft (~553 ft elevation), and the log data from several of the boreholes indicated significant ^{60}Co contamination at total depth (DOE 1997a). In borehole 22-00-03, ^{60}Co was detected at a log depth of 145 ft (507 ft elevation), at the bottom of the borehole. The maximum depth extent of the BY Tank Farm ^{60}Co contamination plumes is not known; therefore, any impacts of the vadose zone contamination on the groundwater cannot be directly determined. The depth to groundwater beneath the BY Tank Farm is about 250 ft (402 ft elevation), which is significantly deeper than all but one of the tank monitoring boreholes.

DOE (2000c) reported that the ^{137}Cs and ^{60}Co, detected in borehole 22-02-07 (299-E33-9, Figure 2) in the sediments below the water table, may be affecting the groundwater quality beneath the BY Tank Farm. Groundwater samples collected from this well in December 1999 confirmed the presence of ^{60}Co. These samples suggest that tank waste may be affecting groundwater at this location (Luttrell 2000). ^{60}Co was also identified above the current water table from 175 to 195 ft log depth (479 to 459 ft elevation) and from 208 to 213 ft (446 to 441 ft elevation) in borehole 22-02-07 (299-E33-9). However, due to the limited depths of other boreholes within the BY Tank Farm, the source of these contaminants could not be positively identified.

Repeat logging measurements were acquired in nine boreholes acquired approximately 4 years after the initial baseline data were collected (DOE 2000c). These boreholes were selected for repeat logging to check for contaminant movement, to investigate total gamma anomalies, and to collect data from intervals that were affected by instrument problems during the baseline logging. Indications of possible contaminant movement were observed in two boreholes. Analysis of historical gross gamma logging data by Randall and Price (1998) provided evidence of past and/or present unstable contaminant zones in 26 boreholes in the BY Tank Farm. Routine monitoring with the RAS suggests that ^{60}Co migration may be continuing in four boreholes (Table 3-3).

3.6.2 216-B-35 to -42 Trenches (BX Trenches)

Fecht et al. (1977) evaluated the historical gross gamma-ray logs acquired in the BX Trenches and identified elevated gamma-ray activity from the ground surface to a depth of about 60 ft (~604 ft elevation). No evidence of vertical or horizontal contamination migration was identified. Elevated activity was observed in the groundwater beneath the 216-B-35 through -41 Trenches in all three monitoring wells (299-E33-8, 299-E33-10, and 299-E33-21; Figure 2). Thomas et al. (1956) reported that "*Past history of groundwater contamination has shown the radioactivity to be essentially all due to ^{106}Ru/^{106}Rh*." Fecht et al. (1977) indicated that no conclusive evidence was available to determine that the trenches were the source of the contamination.

The 216-BY Cribs or BY Tank Farm (located approximately 900 and 400 ft northeast of the 216-B-35 through -41 Trenches, respectively) were postulated as sources of the groundwater contamination under the BX Trenches (DOE 1993a). Gross gamma-ray logs from wells and boreholes associated with the 216-BY Cribs indicated contamination occurred throughout the depth extent of the crib monitoring wells and boreholes, indicating that waste from the cribs contributed to the groundwater contamination. Observations of the gross gamma-ray data acquired in several groundwater monitoring wells adjacent to the 216-B-35 through -41 Trenches indicated that radioactive contamination appeared to be migrating in a southerly direction in the unconfined aquifer along the top of the basalt (DOE 1993a).

In the vicinity of the BX Trenches, spectral gamma logging DOE (2002a) detected ^{137}Cs and minor amounts of ^{60}Co. ^{125}Sb was detected in one groundwater monitoring well (299-E33-8) in the upper vadose zone (less than 50 ft bgs or 604 ft elevattion). $^{152/154}$Eu and $^{235/238}$U were not detected in any of the boreholes. Significant changes in contaminant profile are not evident during the last 10 years. Historical gross gamma logs and recent logging results for groundwater monitoring well 299-E33-21 and the total discharge volume indicate the discharges to the 216-B-37 Trench most likely reached groundwater. Survey instrument readings on soil samples (Haney and Honstead 1958) obtained during drilling well 299-E33-21 varied from 50,000 counts per minute (cpm) at the bottom of the trench to 0 cpm at the 80.0-ft depth (590 ft elevation). The Hanford H1/H2 contact may act as a potential spreading surface in the vadose zone. Haney and Honstead (1958) indicated that the 216-B-42 Trench (also known as the 241-BX-8 Grave) contaminated groundwater for a period of one month.

Comparison of spectral gamma data collected in seven boreholes in the 1990s and 2002 shows good agreement between the logging systems (DOE 2002a). The data collected in the 1990s were decayed to the date of the latest SGLS or HRLS logging event in 2002. On the basis of these comparisons, the apparent concentrations for the man-made radionuclides show good agreement between the logging systems when the decayed concentrations are above the SGLS MDL. Other than radioactive decay, no significant changes in contaminant profile have appeared to occur over the time periods between log events (three to ten years) in any of the boreholes. Because these logs were all collected well after discharges to the trenches had ceased, the observed contaminant distribution was probably established during or shortly after the time the trenches were in service and appears to have stabilized over the intervening years.

The recently completed *Remedial Investigation Report for 200-TW-1 and 200-TW-2 Operable Units (includes the 200-PW-5 OU)* (DOE 2003b) characterized the 216-B-38 Trench and performed a risk assessment of the trench. Modeling of the 216-B-38 Trench suggested that uranium isotopes are the only radiological constituent that will reach groundwater in excess of MCLs and that these isotopes would not arrive at the water table for several hundred years, if at all (DOE 2003b). Under the analogous site approach, the 216-B-38 Trench is the representative site for the 216-B-35 through -42 Trenches.

3.6.3 216-B-43 to-50, -57, and -61 Cribs

Gross gamma logs acquired in 1959 and 1963 in the BY Cribs (Raymond and McGhan 1964) showed the entire soil column was highly contaminated to groundwater. The 1963 logs indicated significant decay of radionuclides between 1959 and 1963. Data acquired from borehole 299-E33-7 (Figure 2) indicated contamination between log depths of 100 and 160 ft (531 and 471 ft elevation) in 1959, prior to the initiation of waste disposal in the 216-B-50 Crib in 1965 (Tillson and McGhan 1969). Contamination at this borehole extended to groundwater by the 1976 log date (Fecht et al. 1977).

Geophysical logging was performed in 27 boreholes in the 216-B-43 through -50 Cribs and the 216-B-57 and -61 Cribs by Westinghouse Hanford Company during 1991 and 1992 using the Radionuclide Logging System (RLS). A description of the activity and the results of the surveys are presented in Price (1992) and summarized in DOE (1993b). In 1992, a Phase I Remedial Investigation for the BP-1 Operable Unit (DOE 1993b) included soil borings, geophysical logging, and collection of soil samples. This study concluded that contamination was generally confined to

the area beneath the cribs and that significant lateral migration due to perched groundwater conditions did not appear to have occurred. Below 50 ft (581 ft elevation), concentration levels were observed to decline until a depth of 100 ft (531 ft elevation), at which concentrations remained uniformly low throughout the remainder of the vadose zone.

Brodeur et al. (1993) evaluated the 216-B-57 and 216-B-61 Cribs using logs acquired for the *B Plant Source Aggregate Area Management Study Report* (DOE 1993a) and the 200-BP-1 remedial investigation (DOE 1993b). Boreholes evaluated included 299-E33-24, -304, -305, and -306 (Figure B-5) for the 216-B-57 Crib and 299-E33-25 and -26 for the 216-B-61 Crib. Brodeur et al. (1993) determined a high ^{137}Cs contamination zone exists between the 30- and 60-ft log depth (610 and 580 ft elevation) that is a result of effluent released in the 216-B-57 Crib and very little migration of contaminants has occurred since the site was closed. Brodeur et al. (1993) stated that the ^{137}Cs and ^{60}Co contamination detected in borehole 299-E33-24 in the vadose zone just above the groundwater and within the groundwater migrated to this location from another site. An evaluation of the geophysical logs from the vicinity of the 216-B-61 Crib suggested near-surface contamination and deep ^{60}Co contamination in the area of groundwater. Brodeur et al. (1993) concluded that the deep contamination was carried by the groundwater from another site.

Szwartz (1996) summarized results of geophysical logging in four shallow (e.g., < 50 ft) characterization boreholes drilled into the 216-B-57 Crib in 1993. The logging results suggested minor (i.e., < 4 pCi/g) ^{137}Cs contamination near the ground surface; one borehole exhibited a maximum ^{137}Cs concentration of 3 pCi/g at a depth of 32 ft (608 ft elevation). This detection of ^{137}Cs approximately 72 ft west of the influent point near the center of the crib was believed to be "*a product of horizontal migration from the 216-B-57 Crib*" (Szwartz 1996).

PNNL (1999) and Price (1998) reported that two wells in the BY Crib area (Figure 2) showed small changes (a maximum of 2.6 pCi/g) of ^{60}Co in the sediment profiles. The changes occurred between 1991 and 1994 in well 299-E33-5 and between 1991 and 1995 in well 299-E33-38. The ^{60}Co movement in well 299-E33-5 appeared to be horizontal, migrating laterally in a fine-grained zone between 109 and 114 ft (530 and 525 ft elevation). The ^{60}Co migration in well 299-E33-38 may have been downward between 122 and 138 ft (513 and 497 ft elevation), but migrating amounts are insignificant (1 pCi/g). The lithology at the depths of these changes beneath the BY Cribs is a thick (~100- to 115-ft) sequence of slightly gravelly sands, sands, and silty sands of the Hanford formation. The sequence contains several discontinuous silt lenses and calcareous horizons.

Using spectral gamma logging, DOE (2003a) reported ^{137}Cs, ^{60}Co, ^{125}Sb, and ^{154}Eu were detected in the boreholes and groundwater wells near the BY Cribs. The predominant contaminant in total activity was ^{137}Cs, which was measured at concentrations up to approximately 10^7 pCi/g. In general, ^{137}Cs contamination directly associated with a specific waste site occurs at depths less than 150 ft (481 ft elevation), although data acquired from two boreholes indicate that ^{137}Cs reached groundwater. ^{60}Co contamination is pervasive with extensive lateral migration throughout the area of the cribs, and ^{60}Co intercepts the groundwater. Soil sample results indicated the gamma emitters ^{60}Co, ^{137}Cs, ^{125}Sb, total uranium (U), non-gamma-emitting radionuclides (strontium-90 [^{90}Sr], ^{99}Tc, and tritium [^{3}H]), and plutonium-239 and -240 ($^{239/240}$Pu), exist in the high gamma activity zones that extend to a depth of approximately 35 ft (~596 ft elevation). Below the high-activity zones, only ^{137}Cs and ^{60}Co exist at any significant concentrations in the vadose zone. ^{99}Tc is present just above the groundwater intercept in two deep boreholes where soil samples (DOE 1993b) were available. ^{99}Tc appears to have followed the same pathway through the vadose zone as ^{60}Co. Below the high-

activity zones, ^{238}U above background (0.3 to 1.5 pCi/g) concentrations was not detected by spectral gamma logging in the vadose zone or reported in the available soil samples (DOE 2003a).

The 216-B-50 Crib is reported as not having been used until 1965, at which time ITS waste was disposed of in the crib. However, contamination was observed in a borehole northwest of the crib as early as 1959. Logging and soil sample results of recent investigations suggest the contaminants in the crib are very similar to that observed in the 216-B-43 to -49 Cribs. The similarities include radiological constituent, concentrations of constituents, ratios between constituents, and depths of deposition. The contamination, according to log and soil sample data, is not consistent with the ITS waste that was disposed of in the 216-B-57 Crib. It appears this crib was utilized at the time the adjacent 216-B-43 to -49 Cribs received waste in 1955 (DOE 2003a).

Lateral migration of ^{60}Co is extensive near the BY Cribs (DOE 2003a). ^{60}Co was detected 220 ft northwest of the 216-B-50 Crib and 286 ft southeast of the 216-B-43 Crib. Comparison of borehole logs acquired in 1992 and 2002 indicates continuing migration of ^{60}Co in the area of the cribs.

The *Remedial Investigation Report for 200-TW-1 and 200-TW-2 Operable Units (includes the 200-PW-5 OU)* (DOE 2003b) included characterization activities associated with the 216-B-46 Crib and 216-B-57 Crib. Modeling at the 216-B-46 Crib suggests that ^{238}U breaks through to groundwater almost immediately (at less than 1.0 E-06 pCi/L), although the peak concentration (approximately 300 pCi/L) does not occur until the end of the 1,000-yr simulation period, when the concentration appears to be stabilizing.

3.6.4 Waste Sites Northeast of the B-BX-BY WMA

Fecht et al. (1977) evaluated boreholes and wastes sites northeast of the B-BX-BY WMA. A major zone of contamination was identified from near the 216-B-8 Crib bottom to about 93 ft (~542 ft elevation). It was concluded that no measurable migration of radionuclides had occurred beneath the crib or tile field and that no breakthrough of contaminants to the groundwater had occurred. This conclusion may be in conflict with the assessment by Raymond and McGhan (1964) that borehole 299-E33-16 (Figure 2), which extends to groundwater, indicated "contamination in most of the borehole." A major zone of contamination was detected between 15 and 72 ft (~625 and ~568 ft elevation) beneath the 216-B-7A&B Cribs. Fecht et al. (1977) concluded no measurable downward migration of radionuclides in the major zone of contamination beneath the cribs had been detected. The crib was reactivated, and 1.13 x 10^7 liters discharged in 1966 and 1967. Apparently, this discharge, 11 years after the crib had been last used, has had little effect on moving the radionuclides previously disposed of to the ground (Fecht et al. 1977). Fecht et al. (1977) concluded that breakthrough to groundwater did not occur at this site. Boreholes 299-E33-19 and -20 (Figure 2) are used to monitor the vadose zone at the 216-B-11B and -11A French Drains, respectively. Fecht et al. (1977) reported contamination at 90 and 75 ft (~562 and ~577 ft elevation) in boreholes 299-E33-19 and -20. It was concluded no measurable migration of radionuclides or breakthrough of contaminants to the groundwater had occurred. Raymond and McGhan (1964) reported low-level contamination existed throughout borehole 299-E33-20 in 1959.

Boreholes were logged in 1992 using WHC's RLS and the Pacific Northwest National Laboratory (PNNL) gross gamma logging system (Brodeur et al. 1993). Data were acquired in boreholes near the 216-B-7A&B Cribs, 216-B-11A&B French Drains, and the 216-B-51 French Drain. Borehole 299-E33-58 was logged with the RLS near the 216-B-7A&B Cribs. In addition, gross gamma logs were collected by PNNL in boreholes 299-E33-58 and -18. The findings that contamination existed

to about 100 ft (~540 ft elevation) below the cribs were similar to the results of previous investigations. The logs for borehole 299-E33-20, adjacent to the 21-B-11A French Drain, indicated three minor zones of ^{137}Cs contamination at about 10, 90, and 190 ft (640, 560, and 460 ft elevation). Based on spectral gamma logging, DOE (2002b) reported detecting ^{137}Cs, ^{60}Co, ^{238}U, ^{235}U, and ^{154}Eu in the boreholes and groundwater wells northeast of the B-BX-BY WMA. The predominant contaminant detected was ^{137}Cs, which was measured at a maximum concentration of 150,000 pCi/g. In general, contamination that appears to be directly associated with a specific waste site was observed at log depths less than 150 ft (~500 ft elevation), although historical gross gamma logging suggests contaminant breakthrough to groundwater may have occurred at some sites prior to 1959. Uranium contamination (Figure 16) was identified trending northeast from near tank BX-102 in the BX Tank Farm to borehole 299-E33-18 (Figure 17) approximately 400 ft to the east-northeast. This area of contamination (Figure 16) was defined by 19 boreholes near tank BX-102 and extended out of the WMA to borehole 299-E33-41 (Figure 18). Processed uranium was detected as deep as the top of the water table (401 ft elevation) and appears to have migrated through the vadose zone as far as 299-E33-18 (DOE 2002b). DOE (2002b) reported the detection of ^{235}U and ^{238}U in borehole 299-E33-59 between elevations of 612 and 600 ft (42 and 54 ft log depth) near the 216-B-7A&B Cribs and that the $^{235/238}$U contamination detected in 299-E33-18 between the elevations of 421 and 401 ft (234 and 254 ft log depth), approximately 80 ft west and up dip from the cribs, appear to be unrelated.

^{60}Co and ^{137}Cs contamination was identified throughout the deep vadose zone in the area northeast of the WMA (DOE 2002b). This contamination was detected just above the current groundwater level and was also detected within the groundwater. However, it is only observed in groundwater wells that were drilled in the 1950s. RCRA-compliant groundwater wells drilled since the early 1990s do not exhibit this contamination. The ^{60}Co and ^{137}Cs are probably the result of historical groundwater contamination that may have originated from the BY Cribs. The ^{60}Co and ^{137}Cs observed in the groundwater wells drilled in the 1950s have been hypothesized to be associated with rust or scale on the steel casing.

At waste sites northeast of the WMA, DOE (2002b) concluded that the observed contaminant distribution appears to have been established during or shortly after the time the sites were in service and has largely stabilized over the intervening years except for the processed uranium in groundwater wells 299-E33-18 and 299-E33-41. As shown in Figure 17, log data collected in 1992 for well 299-E33-18 consisted of a PNNL gross gamma log that showed an interval of relatively high total counts between elevations of about 425 and 413 ft (230 and 242 ft log depth). On the basis of these data, the RLS was used to collect stationary measurements for 300 sec at 236 and 252 ft log depth (419 and 403 ft elevation). ^{60}Co was detected at both depths at less than 3 pCi/g. No $^{235/238}$U or other man-made radionuclides were reported. In 1997, the RLS (Price 1998) was again used to log the entire borehole (Figure 17). ^{60}Co was detected again but $^{235/238}$U was also detected at this time (Price 1998), indicating an influx since 1992. Comparison of the 1997 data with the 2001 SGLS data suggests the ^{60}Co (decayed to 2001) is stable, but the $^{235/238}$U concentrations may have increased since 1997 (DOE 2002b). As shown in Figure 18, groundwater well 299-E33-41 was logged with the RLS in 1991 (Brodeur et al. 1993) and 1997 (Price 1998). As reported in DOE (2002b), comparison of these logs (Figure 18) suggests a significant influx of uranium contamination between log depths of 120 and 247 ft (538 and 411 ft elevation). Price (1998) reported that the uranium in well 299-E33-41 appears to have increased from 200 to 1,000 pCi/g since the 1991 logging event. The SGLS log in 2002 (DOE 2002b) confirms the existence of this uranium

contamination, and comparison with the prior logs suggests the contamination level generally has not significantly increased since the 1997 logging event.

DOE (2002b) speculated that the uranium was mobilized by an external water line leak that created a high moisture zone at about 5 ft above the normal water table in the area northeast of the BX Tank Farm. This contamination apparently reached boreholes 299-E33-41 and -18 between 1991 and 1997. This deep moisture zone identified in borehole 299-E33-41 (Narbutovskih 1998; Wood et al. 2000b) may be related to the deep moisture zone identified at the bottom of borehole C3103 and may contain uranium contamination. Both DOE (2002b) and Pruess and Yabusaki (in Knepp 2002) concluded that uranium migration in the vadose zone may be following the northeast stratigraphic dip in this area.

The *Remedial Investigation Report for 200-TW-1 and 200-TW-2 Operable Units (includes the 200-PW-5 OU)* (DOE 2003b) included characterization activities associated with four representative waste sites that exist in the study area of this summary report. These sites were the 216-B-46 Crib, 216-B-38 Trench, 216-B-57 Crib, and 216-B-7A Crib. It is reported that the only radiological contaminants that will reach groundwater in excess of MCLs from the -7A Crib are the uranium isotopes. The elevated levels of ^{238}U (108 pCi/g) appear to be contained at about 29.5 to 33 ft bgs (618.5 to 615 ft elevation). The uranium isotopes require more than 100 years to reach the water table.

3.6.5 Additional Logging Results

Additional boreholes included in this summary report that were not included in previous reports are four groundwater monitoring wells that were recently logged with the SGLS. Two vadose zone boreholes and five RCRA-compliant groundwater monitoring wells were recently logged with the RLS. Table 3-7 lists the boreholes and groundwater wells that were logged with the SGLS and RLS log results for boreholes not logged with SGLS that are included in this investigation. Log plots and Log Data Reports for the recent SGLS logging were previously released and are available on the Internet at **http://www.gjo.doe.gov/programs/hanf/HTFVZ.html**.

The boreholes and groundwater wells identified in Table 3-7 are associated with the B-BX-BY WMA based on their proximity to the WMA. Also included in the table are the dates the boreholes were drilled, previous logs reviewed for this characterization, the depth intervals (elevation) logged with the SGLS, and a general description of the depths at which specific radionuclides were detected. All boreholes were logged from ground surface to the total depth. The entire lengths of the existing RCRA compliant groundwater wells were not relogged because well construction materials and completion methods precluded accurate measurements and all of these wells have been logged relatively recently (since 1997). Cross sections that include the recently logged boreholes are discussed in Section 5.0, "Interpretation of Results."

Table 3-7. Boreholes and Groundwater Monitoring Wells Logged with the SGLS and HRLS During the Investigation of the B-BX-BY WMA and Adjacent Waste Sites

Borehole	Date Drilled	Previous Logging	Elevation (ft) SGLS Interval Logged (Log Depth in ft)	Elevation (ft) Radionuclides Detected (Log Depth in ft)	Maximum Concentration (pCi/g)
New RCRA Groundwater Monitoring Wells					
299-E33-337	August 2001	Not applicable	663-383 (1-283)	662-661 - ^{137}Cs (1-2)	0.4
299-E33-338	August 2001	Not applicable	657-382 (0-275)	657-655 - ^{137}Cs (0-2)	0.9
299-E33-339	August 2001	Not applicable	664-379 (0-285)	664 - ^{137}Cs (0)	0.7
Existing Groundwater Wells					
299-E28-8	Sept. 1957	1963 [a]	668-358 (2-310)	547, 525 - ^{137}Cs (121, 143) 378-377 - ^{60}Co (290-291) 371 - ^{60}Co (297)	0.3 0.3 0.2
RLS results for New Boreholes (Not Logged by the SGLS)					
299-E33-45	Jan. 2001	2001	658-398 (0-260)	658-656 - ^{137}Cs (0-2) 646 - ^{137}Cs (12) 639, 637 - ^{137}Cs (19, 21) 586-462 - ^{238}U (72-196) 584-482 - ^{235}U (74-176)	2.5 0.2 0.2 230 8
299-E33-46	May 2001	2001	657-393 (0-265)	657-651 - ^{137}Cs (0-6) 604-596 - ^{60}Co (54-61) 525 - ^{60}Co (132) 612-572 - ^{90}Sr (45-85)	2.3 0.2 0.2 > 1,000
RLS Results for RCRA Groundwater Wells (Not Logged by the SGLS)					
299-E33-334	Dec. 1999	1999	667-382 (0-285)	None Detected	
299-E33-335	Feb. 2000	2000	667-385 (0-283)	None Detected	
299-E33-31	Sept. 1989	1989[b], 1997	651-399 (0-254)	651-640 - ^{137}Cs (0-11)	3
299-E33-32	Sept. 1989	1991[b], 1997	663-395 (0-268)	None Detected	
299-E33-42	Nov. 1991	1991[b], 1997	658-398 (0-260)	658-646 - ^{137}Cs (0-12)	0.5

[a] Gross gamma or scintillation probe used prior to 1976
[b] Gross gamma system used between 1976 and 1991
[c] Radionuclide Logging System (RLS) used after 1991

4.0 SGLS Logging Results by Radionuclides

The boreholes and wells used in the vadose zone characterization efforts for the study area include the previous SGLS logging results from 256 boreholes (59 from the Hanford 200 Areas Characterization Project and 197 from the Hanford Tank Farms Vadose Zone Characterization Project) and previous RLS logging results from an additional 17 boreholes. The logging of these boreholes represents more than 70,000 stationary measurements for gamma-emitting radionuclides such as ^{137}Cs, ^{60}Co, ^{152}Eu, ^{154}Eu, ^{125}Sb, ^{238}U, and ^{235}U. The radionuclide concentration values derived from the SGLS and HRLS data reported in the Log Data Reports and RLS data were placed in data files that defined the position of each data point and the nuclide-specific concentration for that point. Because the visualization software can display only 15,000 points at once, the database was collapsed by calculating 5-ft running averages of each radionuclide to reduce the total size of the data set and to facilitate its display. The sphere plots (Figures 19 through 25) show 5-ft running averages of the 0.5-ft or 1-ft assays of 284 boreholes recorded by the SGLS (or RLS) as spheres that are colored and sized to show the position and relative concentrations of each radionuclide. All logs collected for the Hanford Tank Farm Vadose Zone Characterization Project are decayed to a common date of May 1, 2002. The data obtained from the logging in the B, BX, and BY Tank Farms (DOE 1997a, 1998a, 2000a, 2000b, 2000c, and 2000d) and adjacent waste sites (DOE 2002a, 2002b, and 2003a) were previously collapsed from a 0.5-ft sample interval to a 5-ft sample interval, and the radionuclide concentrations that were not considered reflective of actual formation concentrations were removed. Figures 19 through 25 show spatial distributions for each radionuclide detected in the study area.

Three-dimensional sphere plots, which are presented in Figures 19 through 25, provide an enhanced perspective of the contaminant distribution of ^{137}Cs, ^{60}Co, ^{154}Eu, ^{125}Sb, and ^{238}U as detected in 284 boreholes. ^{235}U is not plotted because it co-exists with ^{238}U. Similarly, ^{152}Eu is not plotted because it co-exists with ^{154}Eu. The Z-axis is plotted in elevation above mean sea level (msl) on Figures 19 through 25. ^{90}Sr was detected only near tank B-110, and is not plotted because it is thoroughly discussed in DOE (2002d), Knepp (2002), and DOE (2000a). ^{90}Sr might have been detected in groundwater well 299-E33-10 (Figure 2), located 215 ft (65 m) southwest of the 216-B-42 Trench. The low-level ^{137}Cs concentrations detected in this groundwater well at elevations of 653 and 652 ft (24 and 25 ft log depth) are insufficient to explain the observed increase in total gamma in this interval, suggesting the presence of either a remote gamma source or a strong beta emitter such as ^{90}Sr (DOE 2002d).

4.1 Antimony-125 (^{125}Sb)

^{125}Sb (Figure 19) was detected near tanks BX-101, BX-102, and BY-103, as well as, at the 216-B-41 Trench and BY Cribs. Maximum concentrations do not exceed 10 pCi/g. The highest elevation that ^{125}Sb was detected was at 622 ft (32 ft log depth) in groundwater well 299-E33-8 (Figure 2), located about 70 ft (21 m) north of the 216-B-41 Trench. The lowest elevation that ^{125}Sb was detected was at 532 ft (97 ft log depth) in borehole 299-E33-302 (Figure B-5), located in the 216-B-49 Crib. The most pervasive distribution of ^{125}Sb in the vadose zone is northeast of tanks BX-101 and BX-102.

4.2 Cesium-137 (^{137}Cs)

^{137}Cs was detected in the vadose zone at all of the waste sites and tank farms in the study area. Figures 20 and 21 present three-dimensional sphere plots that provide an enhanced perspective of the contaminant distribution. Maximum concentrations exceed 20 million pCi/g near tanks BX-102 (299-E33-27) and BX-110 (299-E33-223). Concentrations of ^{137}Cs greater than 1 million pCi/g are limited to elevations above 525 ft (~135 ft log depth) underneath the tank farms and the BY Cribs. ^{137}Cs concentrations are less than 200,000 pCi/g underneath the remaining waste sites in the study area. As shown on Figures 20 and 21, ^{137}Cs was detected continuously from the upper vadose zone to near the present groundwater level near tank BX-102 (299-E33-27), 216-B-36 Trench (299-E33-21), 216-B-45 Crib (299-E33-22), and 216-B-46 Crib (299-E33-23). ^{137}Cs was detected intermittently from the upper vadose zone to near the present groundwater level near the 216-B-44 Crib (299-E33-2), 216-B-49 Crib (299-E33-302), and 216-B-50 Crib (299-E33-7). ^{137}Cs was detected at relatively high levels (> 1,000 pCi/g) near the bottom of boreholes (~560 ft elevation or ~100 ft log depth) located near tanks BX-107 (299-E33-222), BX-110 (299-E33-223), and B-110 (299-E33-214).

^{137}Cs contamination was detected a few feet above the current groundwater table in nearly all of the older groundwater monitoring wells (except for 299-E33-12 and 299-E28-8). Activities were less than 10 pCi/g in this interval except near the BY Cribs, where activities were higher. However, ^{137}Cs was not detected at equivalent elevations in recently drilled vadose boreholes 299-E33-45, 299-E33-46, C3103, C3104, and all of the RCRA-compliant groundwater monitoring wells. As discussed in Section 5.3.3, this ^{137}Cs is postulated to be a relict of former contamination absorbed by rust or scale on the casing emplaced by perched water and groundwater.

4.3 Processed Uranium (^{235}U and ^{238}U)

Only 17 of 284 boreholes (Figure 22) encountered processed uranium (^{235}U and ^{238}U). ^{235}U concentrations are generally an order of magnitude less than ^{238}U concentrations. The most extensive area of $^{235/238}$U contamination is located northeast of tank BX-102. This area contains 13 of the 17 boreholes that encountered processed uranium between the elevations of 615 ft (45 ft log depth) at 299-E33-146 and 415 ft (240 ft log depth) at 299-E33-41. ^{238}U concentrations reached 1,000 pCi/g east of tank BX-102 in boreholes 299-E33-134 (21-27-07) and 299-E33-146 (21-27-08). Processed uranium was detected in 299-E33-165 (21-06-05) southeast of tank BX-106 (or northwest of tank BX-102) at elevations between 613 and 599 ft (45 and 59 ft log depth) at concentrations reaching 200 pCi/g. Borehole 299-E33-18, located approximately 80 ft west of the 216-B-7A&B Cribs, exhibited $^{235/238}$U contamination between 421 and 401 ft msl (234 and 254 ft log depth) at concentrations exceeding 500 pCi/g for ^{238}U; groundwater elevation is at 401 ft in this area. Near the 216-B-7B Crib at borehole 299-E33-59, $^{235/238}$U was detected between elevations of 612 and 600 ft (42 and 54 ft log depth) at concentrations of 32 pCi/g for ^{238}U. Processed uranium (^{238}U only) was detected in borehole 299-E33-256 (22-11-08) southwest of tank BY-111 at elevations between 590 and 591 ft (63 and 64 ft log depth) at concentrations reaching 26 pCi/g.

4.4 Europium-152/154 (^{152}Eu and ^{154}Eu)

^{154}Eu was encountered in all three of the tank farms, the 216-B-7A Crib, and the BY Cribs. ^{154}Eu was detected in 21 boreholes (Figure 23) at elevations between 661 and 546 ft (~ 2 ft and 88 ft log depth). The greatest concentration encountered was 127 pCi/g in borehole 299-E33-144 (21-01-01)

at an elevation of 632 ft (28 ft log depth) near tank BX-101. ^{154}Eu was encountered at scattered locations in the tank farms, and relatively close to the ground surface in the BY Tank Farm. Outside of the tank farms, ^{154}Eu was detected only near the 216-B-7A Crib (borehole C3103) and near the 216-B-44, 216-B-45, and 216-B-50 Cribs. The deepest occurrence of ^{154}Eu was at an elevation of 546 ft (88 ft log depth) in borehole 299-E33-3 near the 216-B-44 Crib.

The distribution of ^{152}Eu in the vadose zone is similar to that of ^{154}Eu. ^{152}Eu is chemically identical to and should always be associated with the ^{154}Eu isotope. The ^{152}Eu contamination generally occurs at much lower concentrations than the ^{154}Eu within the vadose zone sediments and may fall below its MDL when associated with low concentrations of ^{154}Eu. Essentially, the ^{154}Eu isotope provides the best representation of the nature and extent of europium contamination within the vadose zone.

4.5 Cobalt-60 (^{60}Co)

The most extensive distribution of ^{60}Co in the vadose zone was detected at the BY Cribs, where ^{60}Co was encountered from the base of the cribs to groundwater. Figures 24 and 25 are three-dimensional sphere plots of the ^{60}Co subsurface distribution that provide an enhanced perspective of the contaminant distribution. At the 216-B-43 (299-E33-1A), -44 (299-E33-2), -45 (299-E33-3), and -50 Cribs (299-E33-7), ^{60}Co was detected continuously from the base of the cribs to groundwater. ^{60}Co was detected near the ground surface in the BY Tank Farm and as deep as an elevation of 304 ft (323 ft log depth) in borehole 299-E33-12, which is located approximately 500 ft east of the 216-B-44 Crib. Other than the BY Cribs, ^{60}Co was usually detected below the base of a waste site or tank and confined to the upper vadose zone. ^{60}Co was usually detected with ^{137}Cs above an elevation of 550 ft (~100 ft log depth), and generally alone deeper in the subsurface. ^{60}Co was detected in nearly all of the older (pre-1970s) groundwater wells at activities ranging from the MDL to 10 pCi/g at depths below the intercepted groundwater table. ^{60}Co is widely distributed just beneath the base of the tanks in BY Tank Farm (Figure 25). An assessment of the extent of ^{60}Co in the deep vadose zone below the tanks in BY Farm is limited by the depths of the boreholes. ^{60}Co is present in the vadose zone at scattered locations in B and BX Tank Farms. Isolated occurrences of ^{60}Co were encountered in the intervals at elevations of 477 to 462 ft (177 to 192 ft log depth) and 445 to 443 ft (209 to 211 ft log depth) in borehole 299-E33-9 and at elevations of 475 to 470 ft (157 to 152 ft log depth) in borehole 299-E33-13 (Figure 24).

5.0 Interpretation of Results

All log data collected from the boreholes and wells in the study area were assembled. Log depths were converted to elevations and correlated in an effort to identify geophysical markers, contaminated zones, and potential contaminant sources. Three cross-sections that pass through the tank farms and connect with groundwater wells (single-cased) in the vicinity of the B, BX, and BY Tank Farms and adjacent waste sites were constructed from spectral gamma logs collected within the study area between 1995 and 2002. A fourth cross-section was constructed that includes double-cased groundwater wells and illustrates contaminated zones in the deep vadose zone and potential contaminant sources.

C Tech Development Corporation's Environmental Visualization System (EVS) was used to create visualizations of the subsurface distributions of gamma-emitting radionuclides. Visualizations generated by EVS were then selected for the report and exported to a graphics program for annotation and final presentation.

An interpretation regarding the nature and extent of contamination for the area that incorporates the cross sections, visualizations, and historical data is presented. This interpretation also presents possible sources of the contamination and the related impacts to groundwater.

5.1 Geophysical Correlation

The purpose of the geophysical correlation was to identify and correlate sedimentary features between boreholes that may influence the migration of contaminants in the vadose zone. The data acquired from the boreholes were interpreted and correlated with existing geophysical and stratigraphic models for the surrounding area. A simplified stratigraphic model for the B-BX-BY WMA was used as a starting point (Figure 3) to identify potential geophysical markers. The spectral gamma-ray logs for the naturally occurring isotopes (^{40}K, ^{238}U, and ^{232}Th) and total gamma logs for each borehole were compared and correlated with those from surrounding boreholes and checked for the presence of man-made radionuclides. After noting any influences of man-made radionuclides and changes in casing thickness on the spectral and total gamma logs, geophysical markers were identified.

Within the study area, four cross sections were constructed from spectral gamma logs and are shown on Cross Sections A-A' (Figures 26a and 26b), B-B' (Figures 27a and 27b), C-C' (Figures 28a and 28b), and D-D' (Figure 29) and correlated with the existing geophysical control in the area. Figure 2 shows the locations of these cross sections. The cross sections serve multiple purposes. They were constructed such that 1) the nature and extent of measured contamination are portrayed near each major waste site, 2) relationships of contamination between sites (if any) are presented, 3) stratigraphic relationships that may affect contamination profiles can be understood, and 4) relationships between probable migratory pathways and probable sources of contamination are identified.

The influence of stratigraphy upon the subsurface distribution of radionuclides near Hanford's waste sites was recognized at least as early as 1948 (Brown and Ruppert 1948). The purpose of correlating the stratigraphic units was to evaluate and account for their effect on lateral spreading. "*Stratification tends to increase spreading of liquids along bedding planes and along contacts between sedimentary units*" (Fecht et al. 1977). The stratigraphic interpretation contained in Appendix B describes the compilation of the stratigraphic interpretations supplied in each individual Log Data Report. Figure B-1 (Appendix B) is a basemap of all the boreholes referenced in this report.

Both the contaminant profile and contaminant concentration are useful as indications of the proximity of boreholes to a contaminant source. For example, intercepts of contamination at a higher elevation suggest closer proximity to a source. Higher relative concentrations may also suggest closer proximity. By evaluating the contaminant profile in conjunction with stratigraphic correlation based on evaluation of natural gamma emitters, it may be possible to identify likely sources and probable migration pathways.

In the absence of man-made radionuclides, gamma-ray log response is generally proportional to abundance of silt and/or clay that may indicate changes in lithology. The new spectral gamma-ray logs are much more useful to interpret stratigraphy than the older gross gamma-ray logs because of better sensitivity to small changes in radioactivity. A far greater advantage is that ^{40}K and ^{232}Th concentrations can be determined from the spectral data. The larger variations in ^{40}K content (about

4 pCi/g) appear to be correlatable between most boreholes. ^{40}K content and ^{232}Th are probably the most reliable stratigraphic indicators.

Variations in natural radionuclides can be used to identify major changes in subsurface lithology. The H1 gravel-dominated facies is identified by a relatively low ^{40}K concentration of about 13 pCi/g and lower total gamma reading. The backfill has a similar geophysical response as the H1, making it virtually indistinguishable from the H1. The H2 sand facies is identified by a marked increase in apparent ^{40}K concentrations to about 18 pCi/g and an increase in total gamma count rate. ^{232}Th concentrations increase slightly (~ 0.2 pCi/g) in the H2 when compared to the H1. In geophysical terms, the top of the Cold Creek unit is defined as a zone of elevated total gamma count rate,which is due to an increase in ^{232}Th concentrations, just above the point where apparent ^{40}K concentrations start to decrease. The Cold Creek Unit contains both fine-grained and coarse-grained sediments. It is identified by the presense of a silty-sand to silt layer that overlies coarse-grained sediments with lower total gamma count rates and ^{40}K concentrations ranging from 12 to 15 pCi/g. Within the Cold Creek Unit, Knepp (2002) and Wood et al. (2000a) have identified a silt layer (Figure 3). On Cross Sections A-A', B-B', and C-C' (Figures 26a, 26b, 27a, 27b, 28a, and 28b), this fine-grained layer (silty-sand to silt) is shaded and is at the top of the Cold Creek Unit. This fine-grained layer is readily identified at elevations ranging between 434 and 452 ft (187 and 225 ft log depth), by a 2- to 4-pCi/g increase in ^{40}K content with a corresponding increase in total gamma count rate and ^{232}Th concentration. This fine-grained layer (silty-sand to silt) is apparent in 28 of the 30 boreholes that are deep enough to intercept the interval. It appears to dip to the northeast at an angle of approximately one degree. Locally correlatable fine-grained layers may exist within each of the Hanford facies associations and the Cold Creek Unit.

SGLS log data from 29 of the 284 boreholes collected in the study area are shown on Cross Sections A-A' (Figures 26a and 26b), B-B' (Figures 27a and 27b), C-C' (Figures 28a and 28b), and D-D' (Figure 29) and are correlated with the existing geophysical control in the surrounding area. Figure 2 shows the locations of these cross sections. Boreholes were selected based upon depth of penetration, location, and casing configuration. Borehole 299-E33-46 (Figure 27b) is the type of log for the study area that demonstrates the typical log character of the lithology.

Cross Section A-A' (Figures 26a and 26b) originates at well 299-E33-335 (Figure 2), which is located east of the southwestern corner of BX Tank Farm and terminates northeast of the 216-B-8 Crib and Tile Field at well 299-E33-14. The stratigraphic dip of both the Hanford and the Cold Creek Unit is toward the northeast at an angle of approximately one degree. The basalt surface is irregular and varies in elevation from 396 ft in the northeast to 385 ft in the southwest (229 and 287 ft log depth). In the Hanford formation, silt layers can be correlated locally from borehole to borehole, but not over the entire length of the cross section. Fine-grained layers are apparent at elevations of 575 and 495 ft (92 and 172 ft log depth) in well 299-E33-335. Locally correlatable layers were present at elevations of 585 ft (~75 ft log depth) in boreholes 299-E33-146 and 299-E33-45, at an elevation of 532 ft in 299-E33-18 (123 ft log depth), 299-E33-17 (103 ft log depth), and 299-E33-41 (126 ft log depth), and at an elevation of 458 ft in wells 299-E33-17 (177 ft log depth) and 299-E33-14 (167 ft log depth). Fine-grained layers were also present at 532 and 488 ft (126 and 170 ft log depth) in well 299-E33-45.

Cross Section B-B' (Figures 27a and 27b) trends northwest-southeast and appears to follow stratigraphic strike for both the Hanford and Cold Creek Unit. The top of the basalt varies from an elevation of 381 ft (282 ft log depth) in the southeast at well 299-E33-337 to an elevation of 396 ft

(240 ft log depth) in the northwest at well 299-E33-26. In the Hanford, fine-grained layers can be identified in individual boreholes, but these layers cannot always be correlated locally from borehole to borehole. The Cold Creek Unit is identifiable in all of these groundwater wells except for well 299-E33-9, which is double cased down to an elevation of 424 ft (220 ft log depth) and shows ^{137}Cs contamination throughout the length of the well. The Cold Creek Unit is identified by the presence of a thin fine-grained layer that overlies coarse-grained sediments with lower total gamma count rates and ^{40}K concentrations ranging from 12 to 15 pCi/g. This fine-grained layer is readily identified at elevations ranging between 440 ft (~210 ft log depth) and 430 ft (~220 ft log depth), by a 2- to 4-pCi/g increase in ^{40}K content with a corresponding increase in total gamma count rate and ^{232}Th concentration. In borehole 299-E33-337, the fine-grained (silty sand to silt) layer defining the top of the Cold Creek Unit appears to be absent based on SGLS data alone, but neutron-moisture log data show an increase in count rate at 448 ft (215 ft log depth) that suggests elevated moisture content in a fine-grained layer.

Cross Section C-C' (Figures 28a and 28b) trends west-east. The top of the basalt varies from an elevation of 381 ft (282 ft log depth) in the center at well 299-E33-337 to an elevation of 392 ft (280 ft log depth) near the west end at well 299-E33-21 and 392 ft (249 ft log depth) in the east at well 299-E33-33. In uncontaminated boreholes, the ^{40}K content appears to dominate the total gamma except in the fine-grained layers where ^{232}Th becomes more important.

Cross Section D-D' (Figure 29) zig zags in a southwest-northeast trend from near the 216-B-41 Trench, through the BY Tank Farm, to the 216-B-43 Crib. This cross-section illustrates the following: 1) The vertical extent of contamination under BY Tank Farm has not been fully characterized; 2) At elevations between 477 and 462 ft (177 and 192 ft log depth), ^{60}Co is detected in the subsurface in an area reaching from the BY Tank Farm to the BY Cribs; 3) At elevations below 427 ft (~225 ft log depth), ^{137}Cs is detected in the subsurface in an area reaching from the 216-B-41 Trench to the BY Cribs; and 4) ^{60}Co concentrations are present a few feet above the present groundwater level and appear to increase until the bottom of the well is reached. Each of these points are discussed in Section 5.3, "Subsurface Contamination."

Structure maps on the Top of Basalt (Figure B-2), Cold Creek Unit (Figure B-3), and Hanford H2 (Figure B-4) are shown in Appendix B. The basalt surface dips from north to south (Figure B-2). The Cold Creek unit dips to the northeast and is relatively flat under the B-BX-BY WMA (Figure B-3). Figure B-4 illustrates the northeast dip of the H2 (the sand-dominated facies association of the Hanford formation), and it appears that portions of the H2 may have been excavated during tank farm construction.

5.2 Development of the Visualizations

Visualizations were prepared to illustrate the extent of vadose zone contamination. Creating the visualizations required developing geostatistical models of the ^{137}Cs, ^{60}Co, and ^{238}U contaminant distributions. Visualizations of contamination in the vicinity of the study area include three-dimensional "sphere plots," which show contamination as detected in boreholes relative to the locations of the waste sites and the study area. The contaminant models are considered empirical models because they are based on data obtained by measuring concentrations at discrete points in the subsurface and extrapolating those values into the nearby subsurface volume. These contaminant models *are not conceptual models* based on assumed waste disposal and contaminant transport

mechanisms. No effort was made to calculate hypothetical distributions using contaminant transport models.

The visualizations are intended to provide the reader with an understanding of how the gamma-emitting contaminants may be distributed in the vadose zone sediments. The visualizations may also provide an assessment of the extent to which operations may have contributed to contaminant distribution and to define areas of concern for subsequent investigation.

5.2.1 Development of the Interpreted Data Set

The radionuclide concentration values derived from the SGLS and HRLS data were placed in data files that defined the position of each data point and the nuclide-specific concentration for that point. These data files were edited to create an "Interpreted Data Set" that was used to create the visualizations. The concentration data were collapsed by averaging the 0.5-ft (or 1-ft) data points over a 5-ft interval and combined with the "interpreted data set" of SGLS data from the Hanford Tank Farm Baseline Characterization Project (DOE 2000b, 2000c, and 2000d) and Hanford 200 Areas Baseline Characterization Project (DOE 2002a, 2002b, and 2003a). Shape factor analysis, which in certain situations can distinguish contamination in the formation from contamination that is related to the borehole casing (e.g., dragdown of contamination during drilling), was not used because the casing thicknesses were variable and not consistent with the 6-in.-diameter, 0.28-in.-thick casing for which the technique was developed (Wilson 1997). Log run overlaps are eliminated, and SGLS data are replaced with HRLS data where appropriate.

The SGLS data (DOE 2000b, 2000c, and 2000d) from the Hanford Tank Farms Baseline Characterization Project were previously revised by removing radionuclide concentrations that were not considered reflective of actual formation concentrations. The interpreted data set reflects interpretations of the radiological contamination based on familiarity with the distribution of contaminants gained from experience with many SGLS logs. Specific data points may have been removed from the interpreted data set if they are judged to represent contamination on the outside of the casing resulting from "dragdown" during drilling, internal casing contamination from a variety of sources, or contamination that either appears to be localized to the borehole or that may be from a remote source, such as a buried pipeline. The resultant concentration data are collectively referred to as the "interpreted data set."

5.2.2 Three-Dimensional Visualizations

The distribution of boreholes within the study area was used to develop a three-dimensional model using a kriging algorithm. Although kriging algorithms can be used to extrapolate data, they are most effective when data points are uniformly distributed; the uncertainty increases with distance from known points. Visualizations are dependent on parameter selection as well as the subsurface data. Thus, many different visualizations are possible based on any one singular data set. EVS was used to model the surfaces of the geologic layers (Figures B-2, B-3, and B-4), which provide the framework for kriging of properties within each geologic unit for the radionuclide concentration data. The radionuclide concentration data were input to EVS subroutines that created a quadrilateral finite-element grid with kriged nodal values and output these data for viewing. Because nodes were set up at all data sampling points, the extent of the models for the visualizations was governed by the positions of the boreholes. The model does not extrapolate beyond the extent of either the assumed

range value or the kriging extent. As a result, both the model and the visualizations can only extend to the maximum depth of the boreholes and the extent of the geostatistical range.

The kriging software applied an "anisotropy ratio" that allowed the user to adjust the way values are extrapolated. The anisotropy ratio applied a bias to horizontal distances over vertical distances. The program default is 10, which means that vertical distances were multiplied by a factor of 10 before the distance between the grid point and the data point was calculated. A data point 1 ft above or below the grid point will thus appear to be 10 times farther away than a data point 1 ft away at the same level. The effect is to lessen the influence of additional data points in the same borehole. The anisotropy "forces" the kriging algorithm to give more weight to data points at the same level. The default anisotropy ratio of 10 was used to generate the visualizations.

Waste sites (e.g. cribs and trenches) were visualized by creating solid rectangular three-dimensional surfaces at the locations of the waste site centers. The extrapolation is not affected by the insertion of the waste sites; a borehole directly across a waste site still influences the node-point concentration calculation. Tanks were visualized by creating solid cylinderical three-dimensional surfaces at the locations of the tank centers. The waste sites and tanks are displayed in all of the visualizations as being partially transparent.

The EVS software is an "expert" system that automatically determines parameter settings for the geostatistical model and for the kriging operation. These settings were used as a starting point for refinement of the model. Parameters were initially calculated by the software and then refined to create the most representative models for the ^{137}Cs, ^{238}U, and ^{60}Co distributions. Because ^{125}Sb and $^{152/154}$Eu were detected at low concentrations and at a few locations in conjunction with other radionuclides, their distributions are only shown on the sphere plots (Figures 19 and 23). The visualizations of the ^{137}Cs distribution are shown on Figures 30 and 31. The visualizations of the ^{238}U and ^{60}Co distributions are shown on Figures 32 and 33, respectively. Figures 30, 31, 32, and 33 are discussed as they relate to the waste sites and tank farms in Section 5.3. Other visualizations of these radionuclides presented in Section 5.3 are merely subsets or combinations of those presented in Figures 30, 31, 32, and 33.

5.3 Subsurface Contamination

As noted in Section 4.0, $^{152/154}$Eu, ^{125}Sb, ^{137}Cs, ^{60}Co, and $^{235/238}$U were detected in SGLS logs in the study area. The distribution of radionuclides in the subsurface can be grouped according to origin. After considering the relationships between the sites using the historical log data, cross sections, and visualizations, it was determined the contamination conditions should be summarized and discussed in three areas: 1) the waste sites and tank farms, 2) ^{137}Cs presence in the Cold Creek Unit, and 3) ^{60}Co detected near the bottom of groundwater wells. Visualizations of surface ^{137}Cs, subsurface ^{137}Cs, processed ^{238}U, and ^{60}Co are presented in Figures 30 through 33, respectively. Visualizations showing vadose zone plumes of ^{125}Sb and $^{152/154}$Eu are not presented because of the limited spatial distribution of these radionuclides. The near-surface contamination (within 8 ft of the ground surface) is generally low levels of ^{137}Cs (less than 20 pCi/g) that are thought to have been caused by surface spills during waste transfers. The radionuclides (^{137}Cs, ^{60}Co, $^{152/154}$Eu and ^{125}Sb) detected below the near-surface contamination and at elevations above 580 ft (between 8 and 80 ft bgs) are the result of wastes discharged at waste sites and tank leaks and transfer line leaks. Processed uranium was detected between an elevation of 615 ft (45 ft bgs) and groundwater. The ^{137}Cs and

^{60}Co contamination detected near and below the present groundwater table are the result of contaminant breakthrough to groundwater.

In the B-BX-BY WMA and nearby waste sites, there are five groundwater wells that exhibit ^{137}Cs contamination along nearly the entire length of the boreholes. One of these boreholes (299-E33-27) is near tank BX-102 (BX Tank Farm). Two boreholes (299-E33-22 and 299-E33-23) are in the BY Cribs where a ^{137}Cs groundwater plume was identified by Thomas et al. (1956). The remaining two (299-E33-21 and 299-E33-16) are at the 216-B-36 Trench and the 216-B-8 Crib, respectively. Both of these facilities have been interpreted as sources of waste that broke through to groundwater. In addition, tanks B-110 (B Tank Farm), BX-107, BX-110 (BX Tank Farm), and BY-103 (BY Tank Farm) are near boreholes that exhibit ^{137}Cs contamination over practically the entire length of the borehole. These boreholes range in depth from 100 to 150 ft (~560 to ~510 ft elevation). The vadose zone surrounding these tanks may have more extensive deep vadose zone plumes.

As discussed in Section 5.3.3., the ^{60}Co detected near groundwater (Figure 34) is probably not representative of contamination in the formation. This ^{60}Co (Figure 34) is likely due to the preferential accumulation of ^{60}Co on rust on the casing. Figure 35 is a visualization of the ^{60}Co distribution in the vadose zone with the remnant ^{60}Co plume removed.

5.3.1 Waste Sites

Figure 36 is a composite of ^{137}Cs, ^{60}Co, and ^{238}U vadose zone plumes in the B-BX-BY WMA and adjacent waste sites. ^{137}Cs, ^{60}Co, and processed uranium were the radionulides detected with the largest vadose zone plumes. ^{137}Cs was the most prevalent radionuclide detected (Figures 31 and 32), and ^{60}Co was the most widely dispersed detected radionuclide (Figure 33). ^{137}Cs was detected at the ground surface in nearly every borehole (Figure 31) and in the subsurface at every waste site (Figure 32). ^{60}Co was generally detected deeper in the subsurface than ^{137}Cs and primarily near the BY Cribs and the BY Tank Farm (Figure 33). ^{60}Co was detected at groundwater level in the older groundwater wells (Figure 34). The distribution of processed uranium (Figure 32) is limited to the area northeast of tank BX-102 and boreholes 299-E33-165 (tank BX-106), 299-E33-256 (tank BY-111) and 299-E33-59 (216-B-7B Crib). Summaries of the interpreted impacts of the B-BX-BY WMA and adjacent waste sites in the study area are listed in Table 5-1 and discussed in the following subsections.

Table 5-1. Summary of Vadose Zone Borehole Coverage and Interpreted Impact of the B-BX-BY WMA and Adjacent Waste Sites

Site (Operable Unit)	Vadose Zone Control			Interpreted Impact
	Number of Boreholes	Log Depth (ft)	Elevation (ft)	
Waste Sites West of the BX Tank Farm (BX Trenches)				
216-B-35 (200-TW-2)	1	53	617	Insufficient control.
216-B-36 (200-TW-2)	1	284	387	Possibly broke through to groundwater before 1957; insufficient control. ^{137}Cs from surface to groundwater. ^{137}Cs > 1,000 pCi/g between 658 and 640 ft (14 and 32 ft log depth).
216-B-37 (200-TW-2)	3	284	387	Possibly broke through to groundwater before 1957; insufficient control. ^{137}Cs from surface to groundwater. ^{137}Cs > 1,000 pCi/g between 658 and 640 ft (14 and 32 ft log depth).

Table 5-1. Summary of Vadose Zone Borehole Coverage and Interpreted Impact of the B-BX-BY WMA and Adjacent Waste Sites

Site (Operable Unit)	Vadose Zone Control			Interpreted Impact
	Number of Boreholes	Log Depth (ft)	Elevation (ft)	
216-B-38 (200-TW-2)	8	260	403	Probably did not break through to groundwater. ^{137}Cs > 1,000 pCi/g between 650 and 621 ft (13 and 42 ft bgs). Representative waste site for 200-TW-2 OU.
216-B-39 (200-TW-2)	None			
216-B-40 (200-TW-2)	None			
216-B-41 (200-TW-2)	1	258	391	Insufficient control.
216-B-42 (200-TW-1)	None			Broke through to groundwater (Haney and Honstead 1959).
Waste Sites Northwest of the B-BX-BY WMA (BY Cribs and 216-B- 57 & -61 Cribs)				
216-B-43 Crib (200-TW-1)	4	239	396	^{60}Co from 605 ft (27 ft log depth) to groundwater at concentrations < 1 pCi/g. ^{137}Cs (max > 10^6 pCi/g at 613 ft [19 ft log depth]) from 620 to 535 ft (12 and 97 ft log depth).
216-B-44 Crib (200-TW-1)	5	238	397	^{60}Co from 575 ft (60 ft log depth) to groundwater at concentrations < 1 pCi/g. ^{137}Cs (max > 10^6 pCi/g at 608 ft [27 ft log depth]) from 623 to 488 ft (12 to 147 ft log depth).
216-B-45 Crib (200-TW-1)	5	243	391	^{60}Co from 600 ft (34 ft log depth) to groundwater at concentrations < 10 pCi/g. ^{137}Cs (max ~ 10^7 pCi/g at 612 ft [22 ft log depth]) from 627 ft (7 ft log depth) to groundwater.
216-B-46 Crib (200-TW-1)	5	233	400	^{60}Co from 610 ft (23 ft log depth) to groundwater at concentrations ~ 1 pCi/g. ^{137}Cs (max 10^6 pCi/g at 610 ft) from 625 ft (8 ft log depth) to groundwater. Representative waste site for 200-TW-1 OU.
216-B-47 Crib (200-TW-1)	4	243	396	^{60}Co from 590 to 468 ft (49 to 171 ft log depth) at concentrations < 10 pCi/g. ^{137}Cs (max > 10^6 pCi/g at 613 ft [22 ft log depth]) from 618 ft to 573 ft (27 to 66 ft log depth).
216-B-48 Crib (200-TW-1)	3	242	387	^{60}Co from 610 to 462 ft (20 to 168 ft log depth) at concentrations ~ 1 pCi/g. ^{137}Cs (max > 10^6 pCi/g at 613 ft [17 ft log depth]) from 611 to 573 ft (19 to 57 ft log depth).
216-B-49 Crib (200-TW-1)	4	242	387	^{60}Co from 610 ft (19 ft log depth) to groundwater at concentrations < 1 pCi/g. ^{137}Cs (max > 10^6 pCi/g at 612 ft (17 ft log depth) from 624 to 528 ft (5 to 101 ft log depth).
216-B-50 Crib (200-PW-5)	5	234	397	^{60}Co from 608 ft (21 ft log depth) to groundwater at concentrations < 1 pCi/g. ^{137}Cs (max > 10^6 pCi/g at 612 ft [17 ft log depth]) from 620 to 560 ft (9 to 100 ft log depth). SGLS results indicate that this Crib belongs in the 200-TW-1 Operable Unit.
216-B-57 Crib (200-PW-5)	4	247	395	^{137}Cs (max > 10^4 pCi/g at 609 ft [24 ft log depth]) from 627 to 552 ft (6 to 81 ft log depth). Representative waste site for 200-PW-5 OU.
216-B-61 Crib (200-MW-1)	3	240	397	Not used

Table 5-1. Summary of Vadose Zone Borehole Coverage and Interpreted Impact of the B-BX-BY WMA and Adjacent Waste Sites

Site (Operable Unit)	Vadose Zone Control			Interpreted Impact
	Number of Boreholes	Log Depth (ft)	Elevation (ft)	
216-BY-201 Catch Tank (200-TW-1)	None			
Waste Sites Northeast of the B-BX-BY WMA				
216-B-7A & -7B Cribs (200-TW-2)	5	223	433	Probably did not break through to groundwater based on gross gamma and SGLS logs. ^{137}Cs > 1,000 pCi/g between 635 and 595 ft (17 to 61 ft log depth). Representative waste site for 200-TW-2 OU.
216-B-8 Crib and Tile Field (200-TW-2)	16	258	384	Probably broke through to groundwater before 1959 based on gross gamma logs. ^{137}Cs from 620 to 430 ft (22 to 212 ft log depth). ^{137}Cs > 1,000 pCi/g between 615 and 550 ft (27 to 95 ft log depth).
216-B-51 French Drain (200-TW-1)	None			
216-B-11A&B French Drains (200-PW-5)	2	254	402	Probably broke through to groundwater based on 1959 gross gamma log.
B Tank Farm				
B-101	8	145	512	^{60}Co (1 pCi/g <) at 590 ft (67 ft bgs). ^{137}Cs (~100 pCi/g) at 602 ft (55 ft bgs).
B-103	5	135	520	Minor ^{137}Cs and ^{60}Co below 635 ft (20 ft bgs).
B-105	4	135	523	^{60}Co to 549 ft (110 ft bgs), ^{137}Cs (70,000 pCi/g) at 603 ft (52 ft bgs).
B-107	5	132	526	^{60}Co, ^{154}Eu, ^{137}Cs (1,000 pCi/g) at 621 - 603 ft (37 - 56 ft bgs).
B-110	7	266	391	Possible source of ^{99}Tc in groundwater. ^{137}Cs (> 1,000 pCi/g) between 634 and 538 ft (25 and 107 ft bgs). ^{90}Sr (max 11,000 pCi/g) between 599 and 559 ft (60 and 100 ft bgs).
B-111	5	130	528	^{137}Cs (~ 1 pCi/g) near base of tank.
B-112	6	152	504	^{137}Cs (< 10 pCi/g) to 635 ft (20 ft bgs).
B-201	None			
B-203	None			
B-204	None			
BX Tank Farm				
BX-101	6	122	538	Wastes have commingled with the spill from tank BX-102.
BX-102	19	262	392	Processed uranium reached groundwater by 1994.
BX-106	7	145	513	Probable leaker, ^{137}Cs (>500 pCi/g) at base of tank. ^{238}U (max 200 pCi/g) between 613 and 599 ft (41 and 55 ft bgs).

Table 5-1. Summary of Vadose Zone Borehole Coverage and Interpreted Impact of the B-BX-BY WMA and Adjacent Waste Sites

Site (Operable Unit)	Vadose Zone Control			Interpreted Impact
	Number of Boreholes	Log Depth (ft)	Elevation (ft)	
BX-107	5	102	558	Full extent of ^{137}Cs vadose zone plume is unknown. ^{137}Cs (> 1,000 pCi/g) between 625 and 558 ft (25 and 102 ft bgs). Maximum concentration of 1 million pCi/g at 616 ft (44 ft bgs).
BX-108	9	130	529	^{137}Cs (~ 1,000 pCi/g) at 652 ft (7 ft bgs). ^{137}Cs at 557 ft (100 ft bgs) may be from tank BX-111. ^{60}Co (< 1 pCi/g) between 625 and 582 ft (34 and 77 ft bgs).
BX-110	6	100	560	Full extent of ^{137}Cs vadose zone plume is unknown. ^{137}Cs > 10 million pCi/g at 648 ft (12 ft bgs). ^{137}Cs > 1,000 pCi/g between 582 and 574 ft (78 and 86 ft bgs).
BX-111	10	145	517	Full extent of ^{137}Cs in the vadose zone is unknown. ^{137}Cs > 100,000 pCi/g between 620 and 617 ft (39 and 42 ft bgs). ^{137}Cs > 1,000 pCi/g between 592 and 593 ft (67 and 68 ft bgs). SW of the tank, ^{60}Co (~ 1 pCi/g) between 610 and 585 ft (50 and 75 ft log depth) at borehole 21-00-21.
BY Tank Farm				
BY-103	11	150	503	Full extent of ^{137}Cs and ^{60}Co in the vadose zone is unknown. ^{137}Cs > 10 million pCi/g between 618 and 620 ft (33 and 35 ft bgs). ^{137}Cs > 1,000 pCi/g to 570 ft (82 ft bgs). ^{60}Co (~ 1 pCi/g or less) between 607 and 506 ft (56 and 147 ft bgs).
BY-105	5	150	503	^{60}Co (~ 1 pCi/g or less) between 624 and 553 ft (28 and 103 ft bgs).
BY-106	6	135	517	^{60}Co (maximum 10 pCi/g) between 624 and 553 ft (28 and 98 ft bgs).
BY-107	6	100	553	Full extent of ^{60}Co in the vadose zone is unknown. ^{60}Co (~ 1 pCi/g or less) between 622 and 553 ft (31 and 100 ft bgs).
BY-108	7	150	503	Full extent of ^{60}Co in the vadose zone is unknown. ^{60}Co (~ 1 pCi/g or less) between 625 and 553 ft (28 and 103 bgs).
BY-111	5	100	553	Possible leaker. ^{60}Co < 1 pCi/g between 626 and 597 ft (27 and 56 ft bgs). 26 pCi/g of ^{238}U at 591 ft (62 ft bgs).
BY-201	None			
BY Tank Farm				Extensive ^{137}Cs contamination within a few feet of the ground surface at concentrations of more than 1,000 pCi/g.

5.3.1.1 BX Trenches

^{137}Cs, ^{60}Co, and ^{125}Sb were the only radionuclides detected in boreholes near the BX Trenches. ^{137}Cs was detected in every well and borehole. ^{60}Co was detected at the 216-B-36 and -38 Trenches and north of the 216-B-41 Trench at elevations between 623 and 592 (log depths from 30 to 72 ft) at activities ranging from 0.1 to 0.6 pCi/g. At depths below the groundwater table, ^{60}Co was detected at activities ranging from 0.1 to 0.3 pCi/g in all of the groundwater wells. ^{125}Sb was detected only in borehole 299-E33-8, at elevations between 622 and 620 ft (32 and 34 ft log depth) with activities ranging from 1 pCi/g to 2.5 pCi/g. ^{152}Eu, ^{154}Eu, ^{235}U, and ^{238}U were not detected in any of these boreholes.

The 216-B-38 Trench is the representative waste site for the 200-TW-2 operable unit while the full extent of the ^{137}Cs contamination at the BX Trenches (Figure 31) is unknown because three of the

trenches do not have any borehole coverage. The 216-B-38 Trench is the only trench that has been fully characterized, and the majority of the ^{137}Cs contamination is detected immediately beneath the eastern half of the 216-B-38 Trench in the silty sandy to sandy gravels of the H1 unit (DOE 2002a). ^{137}Cs contamination was present below the base of the trench in every borehole; the highest concentrations were detected within about 15 ft below the base of the trench. In the western half of the 216-B-38 Trench, it appears that the vadose zone below the base of the trench is not contaminated due to a relative high in the H1/H2 surface. The H1/H2 surface may control the predominant direction of lateral spreading of the radionuclides at the BX Trenches. Similar geologic conditions exist at the 216-B-35 to -41 Trenches. Based on the April 1954 date of the photograph, Figure 11 is either a picture of the 216-B-36 or -41 Trench and demonstrates that wastes spread past the middle of the trench in the photograph. Thus, the results at the 216-B-38 Trench are probably not applicable to the other trenches.

^{137}Cs contamination was detected a few feet above the current groundwater table in all of the groundwater monitoring wells. Activities ranged from 0.3 to 3.5 pCi/g in this interval, which extends about 25 ft above the current groundwater level. However, ^{137}Cs was not detected at equivalent elevations in the recently drilled vadose borehole C3104 (240- to 260-ft log depth). The deepest ^{137}Cs concentrations were detected below the top of the groundwater at the bottom of well 299-E33-21, where a maximum activity of 45 pCi/g was encountered at an elevation of 392 ft (280-ft log depth). ^{137}Cs contamination was detected continuously from the ground surface to an elevation of 427 ft (log depth of 245 ft) in well 299-E33-21, and Brodeur et al. (1993) concluded that breakthrough to groundwater had occurred. The ^{137}Cs detected near the groundwater table in well 299-E33-8 is not due to dragdown, because the well was drilled before the trenches were in operation, and the zones of major ^{137}Cs contamination are separated by about 150 ft of clean borehole.

Review of historic gross gamma logs suggests that groundwater contained contaminants as early as 1957. The discharges to the 216-B-36 and -37 Trenches may have broken through to groundwater. The ^{137}Cs and ^{60}Co detected near and below the present groundwater table may have been caused by breakthrough of contaminants to groundwater near the 216-B-36 Trench based on the spectral gamma log of 299-E33-21 (Brodeur et al. 1993), or the source of the groundwater contaminants may have been the BY Cribs or BY Tank Farm (DOE 1993a).

5.3.1.2 BY Cribs and 216-B-57 and -61 Cribs

The gamma-emitting radionuclides ^{137}Cs, ^{60}Co, ^{125}Sb, and ^{154}Eu were detected while logging northwest of the B-BX-BY WMA (Figure B-5). In addition to these radionuclides, total U was also detected in soil samples (DOE 1993b) during previous characterization efforts. Each site except for the 216-B-61 Crib, which was never used, exhibited ^{137}Cs as a significant contaminant, with the highest concentration measuring about 10^7 pCi/g south of the 216-B-45 Crib. ^{60}Co contamination is laterally pervasive in the vadose zone and reaches the groundwater below the 216-B-43 to -50 Cribs. Based on the SGLS logging, all of the BY Cribs appear to have received similar waste streams and that characterization results collected at the 216-B-46 Crib are applicable under the analogous site concept (DOE 1999a) to the all of the BY Cribs. Currently, the 216-B-50 Crib is grouped with the 200-PW-5 Operable Unit; however, SGLS results there are consistent with nearby Cribs that are in the 200-TW-1 Operable Unit. Historical log information collected after 1959 indicates contaminant breakthrough to the groundwater in the vicinity of all the 216-B-43 to -50 Cribs. However, the 216-B-47 and -48 Cribs did not have deep boreholes to groundwater close enough to the cribs such

that an evaluation could be made. Figures 31, 32, and 33 show that the dominant contaminant in the 216-B-57 Crib is ^{137}Cs and that no contamination appears to have entered the groundwater from this crib. No evidence of breakthrough to the groundwater at the 216-B-57 Crib was indicated.

Another site in the area that contained waste is the 216-BY-201 Catch Tank. Although there was a release (WIDS) associated with this site, limited cleanup occurred in the top few feet of the site. There are no boreholes in close proximity and the impact of this site cannot be evaluated.

The profiles for each crib borehole indicate relatively high ^{137}Cs concentration zones 20 to 80 ft thick. ^{60}Co contamination is generally continuous throughout the vadose zone down to groundwater. Soil sample results (DOE 1993b) in the BY Cribs show non-gamma-emitting radionuclides exist in the high ^{137}Cs concentration zones just below each crib, at elevations between 616 and 600 ft (15 and 31 ft bgs). These radionuclides include ^{90}Sr, ^{99}Tc, $^{239/240}$Pu, and ^{3}H. In two deep boreholes where soil samples (DOE 1993b) were collected, ^{99}Tc detected near the top of the groundwater appears to have followed the same pathway in the vadose zone as ^{60}Co. On the basis of all the data reviewed, ^{60}Co and ^{99}Tc may continue to impact the groundwater underlying the cribs (DOE 2003a). Radionuclide contamination currently shown to exist in groundwater includes ^{99}Tc, ^{60}Co, and uranium (PNNL 2003). Uranium is not detected in the vadose zone by any spectral gamma logging, and soil samples (DOE 1993b) show total uranium above background concentrations (> 1.5 pCi/g) only in the high ^{137}Cs concentration zones just below the cribs. In these high-activity zones the MDL for uranium using spectral gamma measurements is greatly increased and uranium would not be detected at the maximum concentrations detected with soil samples (i.e., 350 pCi/g). There is no evidence of vadose zone uranium contamination within 190 ft of the groundwater underneath the BY Cribs.

There is evidence of extensive lateral migration of contaminants in the vicinity of the BY Cribs (Figures 31 and 33). The full extent of contamination cannot be determined because of the relatively sparse distribution of boreholes. ^{60}Co contamination is observed over a distance of 600 ft between boreholes 299-E33-40 and -13. Figures 31 and 33 suggest no influence or commingling of contaminants from the 216-B-43 to -50 Cribs with those from the 216-B-57 Crib and that the 216-B-61 Crib was not used. No borehole coverage exists immediately to the north of the cribs, and the BY Tank Farm boreholes are not deep enough (Figure 33) to determine if crib contamination extends southward or tank farm contamination extends northward to commingle with crib contamination. On the basis of the stratigraphic dip at one degree to the north in the area (DOE 1993b), the BY Tank Farm contamination would be expected to invade the area of the cribs.

Borehole 299-E33-13, located southeast of the cribs and northeast of the BY Tank Farm, exhibits residual ^{60}Co contamination in the interval between the elevations of 476 and 471 ft (156 to 161 ft log depth). It cannot be determined if this contamination originated from the tank farm, the cribs, or both. The boreholes in the BY Tank Farm are not generally deep enough to determine if tank leaks have spread north of the farm. The contamination profile of the only deep borehole (299-E33-9; Cross Section D-D', Figure 29) in BY Tank Farm shows ^{60}Co contamination at an elevation of 475 ft (179 ft log depth) and ^{137}Cs at 425 ft (229 ft log depth). These elevations and contaminants correspond with that observed in borehole 299-E33-13 (Cross Section D-D', Figure 29), which is located 380 ft northeast of borehole 299-E33-9. The concentrations for ^{60}Co and ^{137}Cs at these depth intervals are approximately 3 and 100 pCi/g and 1 and 10 pCi/g for boreholes 299-E33-9 and 299-E33-13, respectively. The source of this contamination is uncertain.

^{60}Co contamination extends laterally from 175 ft to the northwest of the center of 216-B-50 Crib to 165 ft southeast of the 216-B-43 Crib (Figure 33). Borehole 299-E33-40 shows lateral migration to the northwest possibly from the nearest crib (216-B-50). Boreholes 299-E33-3, -336, and -90 also appear to indicate lateral migration of ^{137}Cs at an elevation of approximately 565 ft (~66 ft bgs) and ^{60}Co (elevation of 565 ft to total depth of the boreholes) to the east that probably originates from the 216-B-45 Crib (DOE 2003a).

^{137}Cs and ^{60}Co contamination were detected in all deep boreholes drilled in the 1950s at a depth consistent with historical and current water levels. Boreholes drilled to the groundwater in the area since the 1990s did not exhibit any contamination. The source of this ^{60}Co/^{137}Cs contamination is most likely the 216-B-43 to -50 Cribs. Data visualizations (Figures 31 and 33) suggest that the BY Tank Farm may also be a potential source of the contamination. ^{137}Cs and ^{60}Co contamination entered the groundwater in 1955 from the 216-B-43 to -50 Cribs (Thomas et al. 1956). Current log data show a continuous record of these contaminants to the current groundwater level. Many boreholes in the vicinity and in boreholes as far as the 216-B-5 Injection Well (Smith 1980; DOE 2002e) in the southeast and the 216-B-42 Trench (DOE 2002a) to the southwest also exhibit ^{60}Co near the groundwater/vadose zone interface even though there is no continuous record of vadose zone contamination from the high activity zones to the deep vadose zone. This residual contamination is probably largely the result of groundwater contamination from sources such as the BY Cribs that impacted the groundwater as early as 1955. The closest borehole to the 216-B-47 Crib is 299-E33-5, located approximately 37 ft southwest. This borehole exhibits contamination attributed to the crib extending to an elevation of 468 ft (171 ft log depth), well above the current groundwater level. Borehole 299-E33-38 is located approximately 55 ft west of the 216-BY-201 Settling Tank and 70 ft southeast of the 216-B-47 Crib. The RCRA completion of this groundwater well appears to have affected the log profile so that definitive conclusions cannot be drawn regarding the source of contamination. The existence of ^{60}Co throughout much of the borehole is consistent with all cribs in the area, suggesting the source is a crib rather than the settling tank. Boreholes 299-E33-296 and -1A are within and east of the 216-B-43 Crib, 13 ft apart. The contaminant profiles suggest contamination entered the groundwater below this site. Borehole 299-E33-13, located 285 ft from the 216-B-43 Crib, indicates sporadic ^{60}Co contamination. An interval at approximately 475 ft in elevation (157 ft log depth) suggests lateral movement of contaminants. It is not known if this contamination originated from the BY Tank Farm or the cribs. Between elevations of approximately 425 and 395 ft (~206 and 236 ft bgs), low levels (between 0.1 and 20 pCi/g) of ^{137}Cs and ^{60}Co are observed in boreholes drilled prior to 1991 (299-E33-1A, -5, -24, and -13). It is postulated a perched water zone may have developed from waste disposal in the BY Cribs to a maximum elevation of 425 ft (~206 ft bgs), and the remnants of contamination have adhered to the casing, resulting in a "bathtub ring" in the older boreholes. As shown on Figure 5, the maximum groundwater level in the area was approximately 410 ft (~221 ft bgs).

A comparison of historical gross gamma logs and current SGLS logs, as well as, a more direct comparison of more recent RLS spectral logs with the SGLS, suggest ^{137}Cs contamination profiles and concentrations at the waste sites are relatively stable over time (DOE 2003a). There is some indication that migration of ^{60}Co contamination continued to occur at least between 1992 and 2001 (Figure 37). This migration occurs at varying depth intervals from borehole to borehole.

Other than radioactive decay, no significant changes in the ^{137}Cs contaminant profiles appear to have occurred in the boreholes over the five to ten years between log events (DOE 2003a). Because these

logs were all collected well after discharges to the waste sites had ceased, the observed ^{137}Cs contaminant distribution appears to have been established during or shortly after the time the sites were in service and has largely stabilized over the intervening years.

However, the distribution of ^{60}Co in the vadose zone appears to have changed since 1992 in some boreholes in the vicinity of the 216-B-43 to -50 Cribs. Figure 37 presents comparisons of ^{60}Co concentrations between 1992 and 2002 in nine boreholes where comparisons could be made. Intervals where possible contaminant increases are observed are delineated. Changes in the ^{60}Co profile just above the groundwater (elevations between 408 and 401 ft [~223 and ~230 ft bgs]) are noticeable in boreholes where comparisons can be made (Figure 37).

Data acquired from two RCRA-compliant groundwater wells (299-E33-38 and -40) indicate significant changes (Figure 37). The first logs were acquired in 1991 before the boreholes were completed as monitoring wells. Subsequent to well completion, ^{60}Co concentrations increased as shown by logs acquired in 1994 and 2002. The well completion materials (grout, bentonite, and tubing) should attenuate gamma rays, thus reducing the calculated concentrations. The RCRA completion is designed to preclude downward migration along the borehole so that the increases in concentrations in these boreholes must be the result of a lateral influx of contamination. The greatest amount of contaminant movement observed in the BY Crib area is observed in these two RCRA compliant wells, which implies that these particular bentonite seals did not prevent contaminant movement.

When the gross gamma logs for the groundwater monitoring wells in the BY Cribs area presented in Raymond and McGhan (1964), Fecht et al. (1977), and Additon et al. (1978) are interpreted based on the results of the SGLS, significant gamma-emitting contamination is observed at or below groundwater level as early as 1956 (DOE 2003a). SGLS results indicate low levels of ^{60}Co, and, in some cases, ^{137}Cs, just above and below the current groundwater level.

5.3.1.3 216-B-7A&B Cribs

^{137}Cs, ^{60}Co, $^{235/238}U$, and ^{154}Eu were detected while logging in the area of the 216-B-7A&B Cribs (Figure B-1). Figures 31, 32, and 33 provide an enhanced perspective of the contaminant distribution of ^{137}Cs, ^{60}Co, and ^{238}U. ^{154}Eu was detected only in borehole C3103 at elevations between 637 and 635 ft (16 and 18 ft bgs). ^{137}Cs contamination is the predominant contaminant detected in the vicinity of these cribs.

^{137}Cs was detected near the ground surface (elevation of about 653 ft) at each borehole in the vicinity of the cribs (Figure 30). The contaminated interval is at elevations ranging from 652 to 641 ft (~1 to 12 ft bgs) and is approximately 11 ft thick with a maximum concentration of about 10 pCi/g. The surface contamination that lies above the base of the cribs is likely from UPR-E-121, where contaminated soil was removed and transported to the vicinity of the 216-B-7A&B Cribs and the 216-B-11A&B French Drains. The contaminated soil was covered with gravel.

^{137}Cs was measured at higher concentrations at elevations ranging between 637 and 573 ft (~16 and ~80 ft bgs) in every borehole except 299-E33-18. The base of each crib is at an elevation of 639 ft (14 ft bgs). The highest concentration of about 300,000 pCi/g was measured in borehole C3103 beginning at a higher elevation (637 ft or 16 ft bgs) than in the other boreholes. Data acquired from boreholes 299-E33-58 and 299-E33-60, northeast and south of borehole C3103, respectively, exhibit

maximum concentrations of about 4,000 pCi/g. The thickest interval (83 ft) of ^{137}Cs contamination is shown east of the cribs in borehole 299-E33-58, and the thinnest interval (29 ft) and least concentration (1,000 pCi/g) is exhibited west of the cribs in borehole 299-E33-59. Borehole 299-E33-75 indicates ^{137}Cs concentrations at about 10,000 pCi/g with the major contaminant zone beginning at a lower elevation (618 ft or 36 ft log depth) in the vadose zone than boreholes in closer proximity to the cribs.

Borehole 299-E33-18 does not appear to exhibit contamination from the cribs and provides a bound to the maximum western extent of contamination. Other boreholes in the area that bound the maximum extent of contamination are 299-E33-72 (north), 299-E33-19 and 299-E33-20 (east), and 20-00-23 (Figure B-1) in the B Tank Farm (south). These boreholes are at relatively large distances from the cribs and thus poorly constrain the actual lateral extent. Figure 31 provides a view of the ^{137}Cs contaminant distribution that indicates the contamination from the 216-B-7A&B Cribs probably does not extend to vicinity of the 216-B-8 Crib or the 216-B-11A&B French Drains. ^{60}Co (Figure 33) was detected only in borehole 299-E33-18 at elevations between 422 and 410 ft (233 and 245 ft log depth), just above the groundwater, and between 403 and 394 ft (252 and 261 ft log depth) partially within the groundwater. This contamination appears to be unrelated to the 216-B-7A&B Cribs (DOE 2002b).

^{235}U and ^{238}U were detected in three boreholes. ^{235}U and ^{238}U were detected with the SGLS in borehole 299-E33-59 between elevations of 612 and 600 ft (42 and 54 ft log depth) slightly above the MDL. In borehole 299-E33-59, processed uranium was not detected in the remaining 77 ft of the borehole below the last indication of processed uranium at an elevation of 600 ft (54 ft log depth). The soil samples collected while drilling borehole C3103 (DOE 2003b) indicated that uranium concentrations between 7.5 and 108 pCi/g were present between the elevations of 631 and 618 ft (22 and 35 ft bgs). In the remainder of the soil column at C3103, uranium concentrations were less than 1 pCi/g and are assumed to be naturally occurring soil concentrations (DOE 2003b). At C3103, the interval containing the elevated uranium also contained high levels of ^{137}Cs, which raised the MDL for uranium, so that processed uranium was not detected in borehole C3103 by the SGLS. Borehole 299-E33-18, located approximately 80 ft west of the cribs, exhibited $^{235/238}$U contamination between 421 and 401 ft (234 and 254 ft log depth); groundwater elevation is at 401 ft in this area. The uranium contamination stranded high in the vadose zone at the 216-B-7A&B Cribs appears to be unrelated to the uranium just above groundwater in well 299-E33-18 (DOE 2002b). This contamination is discussed further in Section 5.3.1.7. Processed uranium was not detected in the two other boreholes (299-E33-58 and -75) in the area.

The area of subsurface contamination is not well defined in the area, particularly for the 216-B-7B Crib. On the basis of data acquired from borehole 299-E33-75, which is located 60 ft north of the 216-B-7B Crib and the northeast stratigraphic dip (Cross Section A-A', Figures 26a and 26b), contamination appears to have spread laterally to the north; a slight eastward component would also be expected. Better definition of the area of contamination would require additional boreholes to be drilled northeast of the cribs approximately equidistant from the area of the 216-B-11A&B French Drains and the cribs.

There is no evidence of breakthrough to the groundwater from this site, but only one deep borehole (C3103) is present in the area. This borehole was drilled in 2001 long after deposition of contaminants between 1946 and 1967, and it did not extend to the groundwater. On the basis of comparison of historical gross gamma logs (299-E33-58, -59, and -75) with the current SGLS data,

the profile of contamination remains about the same as in 1959, indicating no significant movement of gamma-emitting radionuclides through 1976 (Fecht et al. 1977; DOE 2002b).

5.3.1.4 216-B-11A&B French Drains

Boreholes 299-E33-19 and -20 are located near the 216-B-11A&B French Drains. Thin zones of contamination were detected at elevations of 562 and 546 ft (~90 and ~106 ft log depth) and in boreholes 299-E33-19 and -20, respectively. Data acquired from borehole 299-E33-20 indicated intermittent ^{137}Cs contamination near its MDL between elevations of 564 and 448 ft (86 and 202 ft log depth) with an interval between 464 and 453 ft (186 and 197 ft log depth) measuring about 20 pCi/g. Both boreholes indicate ^{137}Cs contamination just above the groundwater level of 401 ft (~251 ft log depth). Intervals of contamination were detected between elevations of 410 and 405 ft (240 and 245 ft log depth) in borehole 299-E33-20 and between 421 and 406 ft (233 and 248 ft log depth) in borehole 299-E33-19. ^{60}Co was detected at intermittent depth intervals between 536 and 520 ft (118 and 134 ft log depth) in borehole 299-E33-19 and at an elevation of 429 ft (221 ft log depth) in the upper vadose zone in borehole 299-E33-20. Both boreholes indicate minor amounts of ^{60}Co just above the current groundwater level.

Based on historical logs in borehole 299-E33-20 (Raymond and McGhan 1964), contamination from the 216-B-11A French Drain may have entered the groundwater prior to 1959. Current SGLS data show ^{60}Co and ^{137}Cs were detected intermittently throughout the borehole below an elevation of 565 ft (85 ft log depth). The contamination is not as extensive in borehole 299-E33-19. Although the contamination was distributed to both French drains, Maxfield (1979) suggested that the majority of contamination probably entered the 216-B-11A French Drain (DOE 1993a). The French drains only extend 40 ft bgs (~610 ft elevation) and did not inject fluid directly into the groundwater (DOE 2002b). The locations of the boreholes northwest and southeast of the French drains are not well suited to intercept contamination that likely would flow along stratigraphic dip to the northeast (Cross Section A-A', Figures 26a and 26b).

5.3.1.5 216-B-8 Crib and Tile Field

Figures 30, 31, 32, and 33 show that ^{137}Cs is the predominant contaminant detected in this area. Contamination is detected near the ground surface between 642- and 629-ft elevation (0 and 13 ft bgs) with a maximum concentration of about 300 pCi/g (Figure 30). A second interval of higher concentration ^{137}Cs contamination (Figure 31) was detected at elevations between 622 and 495 ft (20 and 145 ft bgs). The maximum concentration was about 150,000 pCi/g in borehole 299-E33-67, which is in closest proximity to the 216-B-8 Crib. Borehole 299-E33-89 exhibits the beginning of a major interval of contamination at 621 ft in elevation (23 ft log depth); the bottom of the crib is at 625 ft. The thickest interval of contamination measured near the crib is also in this borehole. Borehole 299-E33-16 (Figure 31) is the deepest borehole in the vicinity of the crib and exhibits almost continuous contamination throughout the borehole. Boreholes located in the tile field northeast of the crib exhibit only near-surface contamination. Historical logs (Raymond and McGhan 1964) of borehole 299-E33-16 indicate contamination entered groundwater sometime prior to 1959 (DOE 2002b).

5.3.2 B-BX-BY WMA

^{137}Cs, ^{60}Co, and processed uranium were detected with the largest vadose zone plumes. ^{137}Cs was detected at the ground surface in nearly every borehole (Figure 31). The subsurface distribution of each of the gamma-emitting radionuclides detected is detailed for each individual tank in the WMA in DOE (1997a, 1998a, and 2000a). ^{60}Co was generally detected deeper in the subsurface than ^{137}Cs, and the most extensive ^{60}Co contamination in the WMA was detected in the BY Tank Farm (Figure 33). ^{60}Co was detected at groundwater level only in the older groundwater well (299-E33-9) within the WMA. Except for two isolated instances, the distribution of processed uranium (Figure 22) is limited to the area northeast of tank BX-102. The BX Tank Farm is discussed first because the contamination in the vadose zone northeast of tank BX-102 can serve as a model for other tank leaks in the WMA. The only tanks discussed in the following subsections are those where new information acquired over the last 3 years would substantially change the interpretation presented in the documents compiled for the Hanford Tank Farms Baseline Characterization Project (DOE 1997a, 1998a, 2000a, 2000b, 2000c, and 2000d) or require more investigation. A summary of the interpreted impacts of the B-BX-BY WMA and adjacent waste sites in the study area are listed in Table 5-1 and discussed in the following subsections.

5.3.2.1 BX Tank Farm

^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu were the gamma-emitting contaminants detected in the BX Tank Farm vadose zone. The majority of the contamination was detected in the eastern portion of the BX Tank Farm, where ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{125}Sb, ^{152}Eu, and ^{154}Eu were detected throughout the 150-ft depths (~510 ft elevation) of several of the boreholes in this area. This contamination is related to leakage primarily from tank BX-102 and secondarily from tank BX-101, both of which are currently designated leakers (Hanlon 2003). It has been determined through groundwater monitoring in well 299-E33-41, located 150 ft northeast of tank BX-102, that contamination resulting from the mobilization of this waste has reached and contaminated groundwater (Knepp 2002; Narbutovskih 1998). Wastes that have leaked from these tanks created complex vadose zone contaminant plumes. The majority of the monitoring boreholes surrounding tanks BX-101 and BX-102 are only 100 ft deep (~560 ft elevation); therefore, the presence and westward extent of these contaminant plumes could not be evaluated. Occurrences of ^{137}Cs, ^{60}Co, ^{125}Sb, ^{152}Eu, and ^{154}Eu were detected around and below the remaining tanks in the BX Tank Farm that are currently designated leakers (BX-108, -110, and -111); however, contamination was not limited to these tanks.

^{137}Cs contamination was detected at the ground surface throughout most of the BX Tank Farm. This contamination most likely resulted from surface spills or leaks from piping systems that were related to routine tank farm operations. The concentrations of most of this ^{137}Cs contamination decreased below the minimum detection limit (MDL) of the logging systems at a depth of 10 ft (~650 ft elevation).

Correlation of intervals of contamination in boreholes in the eastern region of the BX Tank Farm indicates that the fine-grained sediments of the sand-dominated facies association (H2) of the Hanford formation promotes lateral migration of the contaminants. Processed uranium and other mobile radionuclides detected in the BX Tank Farm have migrated hundreds of feet from the contamination source near tank BX-102 and reached groundwater.

5.3.2.1.1 Tank BX-101

Six vadose zone monitoring boreholes surround tank BX-101 (see Figure B-1). These boreholes are 21-01-01, 21-01-02, 21-00-05, 21-02-06, 21-02-07, and 21-04-03. Borehole 21-04-03 is associated with tank BX-104, but is sufficiently close to tank BX-101 to characterize the vadose zone sediments in the vicinity of tank BX-101. Boreholes 21-01-01 (299-E33-144) and 21-01-02 (299-E33-135) were drilled in 1970 to depths of 100 ft (~560 ft elevation) , and borehole 21-00-05 (299-E33-62) was drilled in 1947 to a depth of 150 ft (512 ft elevation). ^{137}Cs and ^{60}Co contamination resulting from leakage from tank BX-101 was detected in boreholes along the southeast quarter of the tank. ^{154}Eu was detected on the northeast side of the tank at borehole 21-01-01 (299-E33-144). Contamination was detected at the depth of the tank base in several boreholes and appears to have commingled with wastes from the spill at BX-102 (Knepp 2002).

Knepp (2002) reported that reevaluation of chemical processing records and spectral gamma data indicate that tank waste discharge into the vadose zone occurred from a pump pit at tank BX-101 between 1968 and 1972. ^{125}Sb, ^{154}Eu, and ^{60}Co were detected high in the vadose zone near tank BX-101 and coincident with uranium from the BX-102 leak in many of the drywells as far as 100 ft east of the tank BX-101. These contaminants (excluding uranium) are likely constituents in the various waste streams that passed through tank BX-101 between 1968 and 1972 and are attributed to the tank BX-101 source.

In the 1970s, repeated influxes of high gamma-ray activity were reported at monitoring borehole 21-01-01 (299-E33-144). In 1972, high gamma-ray activity was detected at depths from about 16 to 30 ft (644 to 630 ft elevation). An investigation into the source of this activity led to the conclusion that it resulted from the 241-BXR-01C Sluice Pit, which is located on top of the dome of tank BX-101 in the northeast quarter of the tank. It was recommended that the tank be designated a suspected leaker (Francis and Borsheim 1972). In 1974, a new zone of elevated gamma-ray activity was detected in borehole 21-01-01 between depths of 56 and 60 ft (604 and 600 ft elevation). An investigation into the source of this activity increase concluded that interstitial liquid may have been leaking from tank BX-101 (Dukelow 1974b). Gross gamma activity increased in borehole 21-01-01 (299-E33-144) at a depth of 52 ft (608 ft elevation) in early 1976. This activity increase was attributed to downward migrating contamination (Jensen 1976).

5.3.2.1.2 Tank BX-102

Tank BX-102 is reported to have lost approximately 91,600 gallons of supernatant containing an estimated 22.5 tons of processed uranium, most likely through a faulty spare inlet port (GE 1951). Anomalous gamma activity was noted in borehole 21-27-11 (299-E33-61) within a few weeks of the spill (Ruppert 1953). This borehole is located about 72 ft northeast of tank BX-102, and it was the only monitoring borehole in the area at the time. Because of the suspected leak in tank BX-102 in 1951, the tank was placed on limited service, but was not emptied or stabilized. The contents were reduced to a level of about 22 in., and this level was maintained during its continued use until 1962. From 1962 to 1968, the waste level was raised to the maximum tank capacity, and only minimal additions or withdrawals were made to the tank contents. The gamma-ray activity in borehole 21-27-11 (299-E33-61) decreased steadily from 1959 through 1968; however, the gamma-ray activity increased in 1969, when the tank was returned to active status, and it continued to increase in 1970. In May 1970, tank BX-102 was pumped to a minimum level and was removed from service. As discussed in Section 3.6, the Womack and Larkin (1971) investigation of the tank leak was

initiated in 1970. The 1951 General Electric Co. report was declassified in 1992, and it is not known if Womack and Larkin were aware that metals waste had been sent to tank BX-102 (Wood et al. 2000a).

Nineteen boreholes surround or are adjacent to tank BX-102 (see Figure B-1). Boreholes 21-02-01, 21-02-03, 21-02-04 (299-E33-27), 21-02-06 (299-E33-143), 21-02-07, and 21-02-11 surround tank BX-102 and were drilled in the 1970s. All of the boreholes were drilled to depths of 100 ft (~560 ft elevation), with the exceptions of boreholes 21-02-04 (299-E33-27), 299-E33-41, and 299-E33-45, which were drilled to groundwater. Boreholes 21-27-01 (299-E33-141), 21-27-02, 21-27-06, 21-27-07, 21-27-08 (299-E33-146), 21-27-09, 21-27-10, 21-27-11 (299-E33-61), 21-00-02, and 299-E33-45 are located east of tank BX-102 and were drilled in the 1970s, with the exceptions of boreholes 21-27-11 (299-E33-61), 299-E33-45, and 21-05-03. Borehole 21-27-11 (299-E33-61) was drilled in 1947, and borehole 299-E33-45 was drilled in 2001 for the B-BX-BY WMA Field Investigation Report (Knepp 2002). Boreholes 21-27-01, 21-27-02, 21-27-06, 21-27-07, and 21-00-02 were drilled to depths of 100 ft (~560 ft elevation), and boreholes 21-27-08, 21-27-09, 21-27-10, and 21-27-11 were drilled to depths of 150 ft (~510 ft elevation).

SGLS logging of 284 boreholes in the vicinity of the B-BX-BY WMA detected processed uranium (^{235}U and ^{238}U) in only 17 boreholes. Thirteen of these boreholes are located in the area immediately northeast of tank BX-102. Processed uranium was detected between the elevations of 615 ft (45 ft log depth at 299-E33-146) and 415 ft (240 ft log depth at 299-E33-41). ^{238}U concentrations reached 1,000 pCi/g east of tank BX-102 in boreholes 299-E33-134 (21-27-07) and 299-E33-146 (21-27-08). Borehole 299-E33-18, located approximately 80 ft west of the 216-B-7A&B Cribs, exhibited $^{235/238}$U contamination between 421 and 401 ft (234 and 254 ft log depth) at concentrations exceeding 500 pCi/g for ^{238}U; groundwater elevation is at 401 ft in this area. Near the 216-B-7B Crib, SGLS logs of borehole 299-E33-59 indicate ^{238}U at a concentration of 32 pCi/g between the elevations of 612 and 600 ft (42 and 54 ft log depth).

MACTEC-ERS conducted a limited repeat logging program in 1999. Logging results indicated that uranium appeared to be moving through the vadose zone in the area to the east of the BX Tank Farm between 1997 and 1999 (DOE 2000b). Log results for borehole 21-27-08 (299-E33-146) appear to indicate an increase in $^{235/238}$U concentrations between 550 and 511.5 ft elevation (110 and 148.5 ft log depth) and an increase in ^{60}Co between 525 and 520 ft elevation (135 and 140 ft log depth). Assessment of gross gamma log data by Randall and Price (1999) suggests that the zones from 568 to 544 ft (92 to 116 ft log depth) and from 530 to 514 ft (130 to 146 ft log depth) have both been stable from 1979 to 1993. Routine drywell monitoring was discontinued in 1994 and was not reinstated until June 2001. Data collected since 2001 do not indicate evidence of significant movement in the vadose zone (see Section 3.6.1, "B-BX-BY WMA").

Cross Section A-A' (Figures 26a and 26b) illustrates the extent of contamination from the spill at tank BX-102. Processed uranium can be traced from borehole 299-E33-27 (21-02-04), which is near tank BX-102, over a distance of 265 ft to well 299-E33-41. The distance between the intervening boreholes in the cross section does not exceed 65 ft. Borehole 299-E33-27 (21-02-04) only exhibits ^{137}Cs contamination. Because of the very high gamma flux caused by ^{137}Cs, uranium and other isotopes cannot be measured. The more mobile uranium can be detected a short distance away in the absence of the ^{137}Cs. SGLS logging conducted by MACTEC-ERS (DOE 2000b) identified uranium contamination east-northeast of tank BX-102 in 1997. The silt layer at an elevation of 488 ft (log

depth of 170 ft) in 299-E33-45 (Figure 26a) appears to retard the downward migration of processed uranium near tank BX-102.

The 1951 spill of processed uranium near tank BX-102 originated near the 4 o'clock position of the tank (borehole 299-E33-27) and has traveled to the northeast along stratigraphic dip (Figures 26a and 26b). In this region of relatively dense well control, it can be tracked as far east as borehole 299-E33-41. At borehole 299-E33-41, processed uranium has reached an elevation of 415 ft (240 ft log depth). Dip is to the northeast (Figures 26a and 26b), and processed uranium was detected near groundwater at borehole 299-E33-18, approximately 242 ft northeast of borehole 299-E33-41. The processed uranium detected in borehole 299-E33-18 is downdip of the tank BX-102 plume extending through 299-E33-41 and updip of the nearby waste sites (216-B-7A and -7B Cribs). The processed uranium in 299-E33-41 was detected prior to the detection of processed uranium in borehole 299-E33-18. Uranium has only been detected at background levels (0.3 to 1.5 pCi/g) in the deep vadose in the nearby waste sites (DOE 2002b and 2003b). A small amount of processed uranium was detected with the SGLS in only one borehole near the 216-B-7B Crib and in soil samples (DOE 2003b) in the recent characterization borehole (C3103). The processed uranium in borehole 299-E33-59 was near the detection limit in the interval between an elevation of 612 and 600 ft (42 and 54 ft log depth) and is unrelated to the processed uranium encountered in borehole 299-E33-18 (DOE 2002b), because the SGLS did not detect processed uranium below an elevation of 600 ft (~53 ft bgs) in C3103, 299-E33-58, -59, and -75. Thus, there is an interval of more than 180 vertical feet separating the relatively minor occurrence of processed uranium near the 216-B-7B Crib and the processed uranium detected near groundwater at well 299-E33-18. The soil samples collected while drilling C3103 (DOE 2003b) indicated that uranium concentrations between 7.5 and 108 pCi/g were present between the elevations of 631 and 618 ft (22 and 35 ft bgs). In the remainder of the soil column at C3103, uranium concentrations were less than 1 pCi/g and are assumed to be naturally occurring soil concentrations (DOE 2003b). Risk modeling for the 216-B-7A Crib suggests that uranium from this crib and analogous cribs will not reach groundwater for more than 100 years (DOE 2003b). Results of prior gross gamma logging do not suggest significant migration of radionuclides in the upper vadose zone near the 216-B-7A&B Cribs.

Because few of the boreholes near tank BX-102 were advanced below 150 ft in depth (~510 ft elevation), the true vertical extent of contamination was unknown until borehole 299-E33-45 was drilled to groundwater in January 2001. This borehole was drilled in the approximate center of known contamination and defines the minimum elevation of the processed uranium near tank BX-102. The SGLS detected uranium contamination to an elevation of 462 ft (log depth of 198 ft). As discussed in Section 3.6, "Previous Investigations," comparisons (Figure 18) of log data from borehole 299-E33-41 indicate an influx of $^{235/238}$U between 1991 and 1997. Perched water (Narbutovskih 1998) was encountered in borehole 299-E33-41 when it was drilled at an elevation of 431 ft (224 ft bgs). Sediments were described as moist to wet for the rest of the section (Narbutovskih 1998). An elevated water table that drained rapidly by about 6.6 ft during a single month was also reported (Narbutovskih 1998).

Borehole 299-E33-41 was drilled between January and April 1991. Wood et al. (2000b) reported the following: *"In the months before well 299-E33-41 was drilled, several flooding events occurred just south of this well's location at the 244-BX-DCRT. The migration through the vadose zone of water from these floods while well 299-E33-41 was being drilled would explain the series of high-radiation concentrations in a series of silt lens from 22.3 m to 73.2 m (73 to 240 ft) and the contaminated*

perched water zone at 68.3 m (224 ft) below the ground surface. The actual water-table surface at this time was 75.3 m (247 ft) from ground surface. Well 299-E33-41 is close to the site of the 113,562 L to 340,687 L (30,000- to 90,000-gal) overflow or spill between tanks 241-BX-103 and -102 in 1951 (DOE 1993). This tank leak is most likely the cause of the contamination and creation of the perched zone because it is only 11.3 m (37 ft) from the well. The nearest crib is 216-B-7B, 91.4 m (300 ft) from the well."

As discussed in Section 3.6, "Previous Investigations," data acquired from borehole 299-E33-18 (Figure 17) also showed an influx of uranium contamination between 1992 and 1997. Uranium concentrations apparently continued to increase between 1997 and 2002. This borehole is located 240 ft east-northeast of borehole 299-E33-41 and appears to be situated down dip. Cross Section A-A' (Figures 26a and 26b) indicates the uranium contamination is migrating laterally and downward through the vadose zone. The perched water zone at 431 ft (224 ft bgs) facilitates the lateral migration of uranium between wells 299-E33-41 and -18. Borehole C3103 was drilled in 2001 for the purpose of characterizing the 216-B-7A&B Cribs and is located about 80 ft from borehole 299-E33-18. High moisture content was encountered in a silt lens at an elevation of about 434 ft (219 ft bgs) and drilling was terminated. This high moisture content is about 3 ft higher in elevation than that encountered in borehole 299-E33-41 in 1991 but it is at the same elevation where contamination increases were indicated when comparing the 1991 and 1997 log data. It is possible the uranium contamination has migrated past the location of borehole C3103 and below the bottom of the borehole (DOE 2002b).

Figure 32 is a visualization of the area of uranium contamination. The contamination is at its highest elevation near tank BX-102. The wells that show recent increases in processed uranium are 299-E33-41 and 299-E33-18. The volume of soil contaminated by processed uranium is shaded green. This visualization (Figure 32) indicates that contamination from the spill at tank BX-102 reached groundwater in the area near wells 299-E33-41 and -18. The data set is limited by a lack of control north of the area of contamination. Logging was not completed with the SGLS in well 299-E33-44 because the sonde was lost (it has since been recovered). This well is located 330 ft north of well 299-E33-41. A sodium-iodide (NaI) system was used to log this well in 1998. No contamination was detected in the well at that time, although the relatively short counting time of 30 sec and the relatively poor resolution typical of NaI systems may not have been sufficient to detect low levels of processed uranium. The location of well 299-E33-44 is key to understanding the northward extent of the uranium contamination. The interpretation shown on Figure 27a indicates that the perched zone present at wells 299-E33-41 and -18 is absent in well 299-E33-44.

The apparent differences in visualization of the uranium spill at tank BX-102 between Figure 16 (DOE 2002b) and Figure 32 are due primarily to the perspective. Figure 16 (DOE 2002b) represents a view from the southeast, and Figure 32 shows a view from the northeast. Other minor differences are due to the use of a geologic model described in Appendix B to develop the visualization in Figure 32.

The interpreted extent of the uranium spill at tank BX-102 varies from the limited extent shown in Figure 15 (Knepp 2002) versus that shown in Figure 16 (DOE 2002b) and Figure 32. This difference is explained by the boreholes included in each respective interpretation. The differences in the extent of the BX-102 uranium vadose zone plume presented in Figure 15 and Figures 16 and 32 occur because Figures 16 and 32 include SGLS results from both inside and outside the B-BX-BY WMA boundary while Figure 15 does not include geophysical data from outside of the BX Tank Farm and

from borehole 299-E33-45. The log results and the soil samples (Knepp 2002) from borehole 299-E33-45 define the vertical extent of the uranium near tank BX-102. If the log results from boreholes 299-E33-45 and 299-E33-41 are excluded from Cross Section A-A' (Figures 26a and 26b), then it would appear that the limit of the uranium resulting from the spill at tank BX-102 is near borehole 299-E33-141 (21-27-01). By excluding the log results from 299-E33-45 and 299-E33-41, both the vertical and lateral extents of the uranium contamination as shown on Figure 15 are underestimated.

The data and interpretations of the groundwater contamination contained within this report were all derived from published sources. Between 1994 and 2000, an extensive uranium groundwater plume has developed in the B-BX-BY WMA as discussed in Section 3.3, "Hydrology". Figure 38 shows the footprint of the tank BX-102 uranium spill in the vadose zone superimposed on the published groundwater map for 1995 (PNNL 1996). Uranium concentrations appear to be at background levels except for well 299-E33-13. This well is located approximately 200 ft southeast of the BY Cribs. The first indications of uranium (above the MCL) in the groundwater occurs in well 299-E33-18 in early 1994 (Figure 9 from PNNL 1998). This well was not sampled for three years following the initial rise in uranium concentrations. Only a limited amount of groundwater samples were collected in 1996 in the vicinity of the B-BX-BY WMA. On the basis of the geophysical logging, the influx of uranium in the deep vadose zone occurred between 1992 and 1997. Unfortunately, groundwater wells 299-E33-18 and 299-E33-41 were not logged in 1994 when the uranium contamination in groundwater was first reported.

Groundwater maps of uranium concentrations in the B-BX-BY WMA were generated from data published in PNNL (2002a). These maps were prepared to present the groundwater data for the years of 1997 (Figure 39) and 1998 (Figure 40), because published groundwater maps of uranium concentrations in the B-BX-BY WMA for the years of 1996 through 1999 were not included in the annual groundwater monitoring reports for those years (PNNL 1997; PNNL 1998; PNNL 1999; and PNNL 2000), or in other groundwater assessments of the B-BX-BY WMA such as Narbutovskih (1998, 2000), Wood et al. (2000a), and Knepp (2002). Figure 39, a map of uranium concentration in groundwater for 1997 based on groundwater data presented in PNNL (2002a), shows two areas with elevated uranium. These areas are based on uranium concentrations observed in boreholes 299-E33-13 and 299-E33-18 (Figure 9). The footprint of the tank BX-102 uranium spill in the vadose zone (shaded pink) is superimposed on the groundwater map (Figure 39). Figure 40, a map of uranium concentration in groundwater for 1998 based on groundwater data presented in PNNL (2002a), shows two areas with elevated uranium. These areas (Figure 40) are based on uranium concentrations observed in boreholes 299-E33-44 and 299-E33-18. Borehole 299-E33-44 was installed in 1998, and, as discussed previously, processed uranium was not detected in the vadose zone. The first groundwater sample collected early in 1998 at borehole 299-E33-44 contained elevated uranium. Figure 41 shows the footprint of the tank BX-102 uranium spill in the vadose zone superimposed on the groundwater map for 2000 (PNNL 2001).

Assessment of data shown on Figures 7, 10, 38, 39, 40, and 41 indicates that uranium concentrations in groundwater are increasing, and groundwater flow appears to be to the northwest. In the 1994 through 2002 time period, uranium concentrations in groundwater have increased, and the uranium plume in groundwater is expanding to the northwest. The uranium groundwater plume appears to originate near wells 299-E33-41 and 299-E33-18. These two wells define the northeastern extent of the tank BX-102 uranium vadose zone plume and have shown increases in uranium concentrations in

the depth interval just above the water table over the last 10 years (Price 1998; PNNL 1999; and DOE 2002b). SGLS logs of 284 boreholes indicate that the processed uranium near tank BX-102 is the only plausible source of uranium in groundwater from the B-BX-BY WMA and adjacent waste sites (Figure 32). Figure 42 summarizes the impact of the spill of 22.5 tons (GE 1951) of uranium near tank BX-102 on groundwater in the study area. In the northwestern portion of the study area, average uranium concentrations in well 299-E33-26 have increased from 9.2 µg/l (in 1994 as shown on Figure 7) to 180 µg/l (in 2002 as shown on Figure 10). Because SGLS data have not idendified other tanks and waste sites as potential sources of uranium contamination in groundwater, the 1951 spill of processed uranium near tank BX-102 is the source of uranium found in the groundwater. This determination, in conjuction with the growth of a uranium groundwater plume to the northwest from the area northeast of tank BX-102, establishes that the groundwater flow direction from 1994 until 2002 was to the northwest. Recent interpretations (PNNL 2003; Knepp 2002) of groundwater data indicate a change in flow direction from northwest or northerly flow to southerly or swinging toward the south and east. This change occurred in the mid-1990's according to Knepp (2002). According to PNNL (2001), … "one could still interpret the distribution of uranium by itself, as indicating northwest flow."

Assessment of the tank BX-102 uranium plume shows that tank wastes can migrate significant distances in the vadose zone and that much of the migration may occur below 100-ft depth (~560 ft elevation), or below the total depth of many of the vadose zone monitoring boreholes in tank farms. The interpreted extent of the uranium spill at tank BX-102 is highly dependent on the depth of the monitoring boreholes. Without the inclusion of the deeper boreholes on Cross Section A-A' (Figures 26a and 26b), the extent of the uranium plume appears to terminate near the shallow borehole 299-E33-141, as shown in Figure 15 (Knepp 2002) and would not be expected to reach groundwater. The deeper boreholes (299-E33-45 and 299-E33-41) demonstrate that uranium contamination is extensive at depth. Because Knepp (2002) did not recognize that the uranium plume extends to borehole 299-E33-41, the environmental impacts of this plume were underestimated in Knepp (2002). The absence of processed uranium in nearly all of the boreholes not associated with the BX-102 plume also suggests that the Hanford Soil Inventory Model (Simpson et al. 2001) may need to be revised, at least in regard to quantities of uranium discharged to the various waste sites.

According to the Hanford Soil Inventory Model (Simpson et al. 2001), processed uranium should have been more widely detected by the SGLS. Figure 43 illustrates the modeled distribution of uranium near the B-BX-BY WMA as reported by Simpson et al. (2001). The Hanford Soil Inventory Model (Simpson et al. 2001) did not estimate releases in the BY Tank Farm, the 215-B-57 Crib, and the 216-B-50 Crib. According to the Hanford Soil Inventory Model (Simpson et al. 2001), the largest single release of uranium is from tank BX-102, followed by the BX Trenches. The SGLS detected uranium in the area northeast of tank BX-102, but did not detect any evidence of processed uranium near the BX Trenches. Substantial inventories (Figure 43) of uranium are predicted by the model for the 216-B-7A&B Cribs, the BY Cribs, and the 216-B-8 Crib and Tile Field. The SGLS detected a minor amount of processed uranium only near the 216-B-7B Crib, where ^{238}U was detected between elevations of 612 and 600 ft (42 and 54 ft log depth) at concentrations of 32 pCi/g at borehole 299-E33-59. As previously discussed, uranium was not detected in the vadose zone by any spectral gamma logging, while soil samples (DOE 2003b) show total uranium above background concentrations only in high ^{137}Cs concentration zones just below the base of the cribs. In Simpson et al. (2001), a comparison was made between a calculated soil data inventory and soil inventory model estimates for the BY Cribs. For the BY Cribs, the SIM-derived estimates were too high, usually about an order of magnitude (Table 5-2).

The ^{60}Co distribution based on SGLS logging in the area also conflicts with the Hanford Soil Inventory Model (Simpson et al. 2001). The Simpson et al. (2001) estimates for ^{60}Co releases to the vadose zone do not agree with the SGLS data. Figure 43 illustrates the modeled distribution of ^{60}Co near the B-BX-BY WMA as reported by the Hanford Soil Inventory Model (Simpson et al. 2001). SGLS logging indicates that the majority of the ^{60}Co contamination in the vadose zone is associated with the BY Cribs, and, to a lesser extent, the BY Tank Farm (Figure 24). Simpson et al. (2001) indicated that the greatest releases of ^{60}Co occurred at B Tank Farm (Figure 43), where a cumulative 2.7 Ci of ^{60}Co were lost to the vadose zone and that only 0.0014 Ci of ^{60}Co were discharged to the vadose zone at the BY Cribs. As depicted in Figure 43, the current estimate of ^{60}Co releases for the BY Cribs appears to be orders of magnitude too low.

Table 5-2. Comparison of Uranium Release Estimates for the B-BX-BY WMA and Adjacent Waste Sites

Waste Site	Total U Estimate in kg (Maxfield 1979)	Total U Estimate in kg (Ci) (Diediker 1999)	Total U Estimate in kg (Williams 1999)	Total U Median Estimate in kg Based on Soil Data (Simpson et al. 2001)	Total U SIM Median Estimate in kg (Simpson et al. 2001)	Total U (Estimate in kg)
B-101					0.393	
B-105					11.1	
B-107					46.2	
B-110					103	
B-201					0.71	
B-203					0.857	
B-204					0.000946	
UPR-200-E-109					1.13	
BX-101					4.43	
BX-102					9430	20,412 (GE 1951)
BX-111					14.2	
216-B-43	14	14 (4.53×10^{-3})	12.5	14	115	13.6 (Fecht et al. 1977)
216-B-44	5.3	2.3 (7.55×10^{-4})	2.2	43.6	308	2.27 (Fecht et al. 1977)
216-B-45	6.8	7 (2.26×10^{-3})	0.7	21.41	267	6.8 (Fecht et al. 1977)
216-B-46	190	190 (6.34×10^{-2})	190	5.95	364	191 (Fecht et al. 1977)
216-B-47	6.8	7 (2.26×10^{-3})	5.7	161.24	203	6.8 (Fecht et al. 1977)
216-B-48	2.3	2.3 (7.55×10^{-4})	1.9	105.45	223	2.27(Fecht et al. 1977)
216-B-49	320	320 (1.06×10^{-1})	311	46.99	367	
216-B-50		< 0.3 (<9.49×10^{-5})				
216-B-57		1 (2.96×10^{-4})				
216-B-7A&B		182 (6.05×10^{-2})			2750	182 (Fecht et al. 1977)
216-B-8 Crib & Tile Field		45 (1.51×10^{-2})			1730	45.4 (Fecht et al. 1977)
216-B-51					0.00002	

Waste Site	Total U Estimate in kg (Maxfield 1979)	Total U Estimate in kg (Ci) (Diediker 1999)	Total U Estimate in kg (Williams 1999)	Total U Median Estimate in kg Based on Soil Data (Simpson et al. 2001)	Total U SIM Median Estimate in kg (Simpson et al. 2001)	Total U (Estimate in kg)
216-B-11A&B		13.6 (4.53×10^{-3})			.01	13.6 (Fecht et al. 1977)
216-B-35	17	16.7 (5.56×10^{-3})			52.1	98.8 (Haney and Honstead 1958)
216-B-36	16	16 (5.31×10^{-3})			64.4	
216-B-38	42	42.3 (1.41×10^{-2})			48.0	
216-B-39	5.8	5.8 (1.93×10^{-3})			49.6	
216-B-40	35	3.5 (1.16×10^{-3})			54.4	
216-B-41	7.5	7.5 (2.5×10^{-3})			47.9	
216-B-37	3.6	3.6 (1.21×10^{-3})			4080	3.6 (Haney and Honstead 1958)
216-B-42	680	679 (2.26×10^{-1})			81.5	7.5 (Fecht et al. 1977)
Total (in kg)					**20,416.9**	**20,985.6**

5.3.2.1.3 Tank BX-106

Tank BX-106 is presently designated sound. However, an isolated plume of contamination containing ^{137}Cs, ^{235}U, ^{238}U, and ^{125}Sb occurs on the south side of the tank at the depth of the tank base. These radionuclides were detected at borehole 21-06-05 (299-E33-165). ^{125}Sb, ^{235}U, and ^{238}U contamination is associated with the ^{137}Cs in this borehole and indicates that tank BX-106 most likely leaked (DOE 1998i).

5.3.2.1.4 Tanks BX-107 and BX-110

Within the BX Tank Farm, the greatest accumulation of ^{137}Cs is in an area between tanks BX-107 and BX-110. This accumulation of ^{137}Cs contamination occurs on the south side of tank BX-107 and is defined by data from borehole 21-07-06. The contamination extends westward to the area east of tank BX-110 by correlation with high ^{137}Cs concentrations in borehole 21-10-03. Tank BX-107 is presently designated sound. Contamination around tank BX-110 consists of ^{60}Co and ^{137}Cs contamination that occurs on the northeast side of the tank at a depth of 40 ft (620 ft elevation), which is the depth of the tank base (DOE 1998m).

The vadose zone around tank BX-110 is monitored with six monitoring boreholes, and tank BX-107 is monitored by an additional four boreholes. Borehole 21-00-07 was drilled in 1948 to a depth of 152 ft (510 ft elevation). Boreholes 21-10-01, 21-10-05, 21-10-07, and 21-10-11 were drilled in 1971 to depths of 100 ft (~560 ft elevation). Boreholes 21-07-03, 21-07-06, and 21-10-03 were drilled in 1973 to a depth of 100 ft. Borehole 21-08-06 was drilled in 1972 to a depth of 100 ft. Borehole 21-04-08 was drilled in 1977 to a depth of 100 ft.

A large plume of ^{137}Cs contamination is shown (Figure 21) southeast of tank BX-110 and southwest of tank BX-107. This plume is defined primarily by data acquired from boreholes 21-10-01, 21-10-03, 21-07-06, and 21-10-05; ^{137}Cs contamination was detected throughout most of the 100-ft lengths of boreholes 21-10-03, 21-01-05, and 21-07-06. The ^{137}Cs concentrations are highest in borehole 21-10-03, where ^{137}Cs concentrations exceeded 10^6 pCi/g at depths between 10 and 23 ft (650 and 637 ft elevation). In borehole 21-07-06, ^{137}Cs concentrations reached 10^6 pCi/g in the interval between 39 and 44 ft bgs (621 and 616 ft elevation). The ^{137}Cs contamination around boreholes 21-07-06 and 21-10-03 was present when the boreholes were logged about a month after borehole construction, and the contamination was likely in place before the boreholes were drilled (DOE 1998a). Boreholes 21-10-01 and 21-10-05 exhibit ^{137}Cs concentration increases at the approximate depth of the tank base, suggesting that the source is leakage from tank BX-110.

^{60}Co contamination was detected in boreholes 21-10-01, 21-10-03, 21-10-05, 21-07-03, 21-08-06, and 21-04-08. The extent of the ^{60}Co contamination in borehole 21-10-03 and 21-07-06 could not be determined because of the high dead times throughout much of the boreholes.

The total vertical extent of the ^{137}Cs and ^{60}Co contamination could not be determined. ^{137}Cs contamination extends to at least the bottoms of boreholes 21-07-06 and 21-10-03 (100 ft). ^{60}Co contamination extends to at least the bottoms of boreholes 21-07-03 and 21-04-08.

According to Welty (1988), test drilling and auguring conducted in 1974 led to the conclusion that the contamination detected in borehole 21-07-06 is associated with a transfer line leak. Because no information or data concerning this transfer line leak or the 1974 investigation were found, it is not possible to assess the results of the 1974 investigation or the validity of that conclusion (DOE 1998a).

The source of the contamination detected in borehole 21-07-06 is highly uncertain. It is possible that the contamination detected in borehole 21-07-06 migrated from a source near tank BX-110, but it is also possible that it is due to another source such as tank BX-107. Further investigation is needed to determine the source of the contamination detected in borehole 21-07-06. The vertical and lateral extents of the plume between tanks BX-110 and BX-107 are not known.

5.3.2.2 B Tank Farm

^{137}Cs was the major gamma-emitting contaminant detected in the B Tank Farm vadose zone. ^{60}Co, ^{154}Eu, and, to a lesser degree, ^{152}Eu, were also detected in the vadose zone sediments. The presence of the beta-emitting radionuclide ^{90}Sr, which was suspected around several boreholes near tank B-110 (DOE 2000a), has been confirmed by the soil sample results collected at borehole 299-E33-46 (Knepp 2002). The contamination identified resulted from tank leaks, piping leaks, and surface spills, and, most likely, a combination of these events (DOE 2000a).

Near-surface ^{137}Cs contamination was detected primarily in the southern portion of the B Tank Farm (Figure 30). This contamination most likely resulted from surface spills that migrated into the backfill material. The maximum near-surface ^{137}Cs contamination was detected in the southeast portion of the tank farm between tanks B-101 and B-104 (Figure 30).

The extensive region of highly concentrated ^{137}Cs contamination detected around borehole 20-10-12 along the north side of tank B-110 likely originated from a leak from the B-110 to B-111 cascade line or from tank B-110 (DOE 2000a). Knepp (2002) attributed the source of this plume to a transfer

line leak. ^{137}Cs contamination (Figure 31) was detected between 636 and 552 ft elevation (23 and 107 ft bgs) around borehole 20-10-12. The location and magnitude of the ^{137}Cs contamination within this region of the vadose zone indicate that this borehole 20-10-12 is very close to the leak source. The plume appears to consist primarily of ^{137}Cs and ^{90}Sr with lesser amounts of ^{60}Co and ^{154}Eu. The ^{137}Cs and ^{154}Eu contamination do not appear to have migrated any great distance laterally from their origin. ^{60}Co contamination (Figure 25) was detected between 590 and 573 ft elevation (67 and 84 ft bgs) around borehole 20-10-02 and at about 607 ft elevation (52 ft bgs) around borehole 20-10-07. These areas of ^{60}Co are probably remnants of a larger contaminant plume that originated from the suspected leak source near the northern side of tank B-110. A distinct zone of ^{137}Cs (Figure 31) and ^{154}Eu (Figure 23) contamination was detected between 639 and 636 ft elevation (20 and 23 ft bgs) around borehole 20-10-07, which is located on the southwest side of tank B-110. Fluctuations in the historical gross gamma-ray activity detected in this borehole over time and the lack of radionuclide contamination below this zone suggest that the contamination detected by the SGLS may be isolated to the region along the inside of one of the inlet lines (DOE 1999i).

The distribution of the potential ^{90}Sr plume is discussed in DOE (2000a, 2002d). Probable ^{90}Sr contamination (DOE 2000a) has been identified at the same depth intervals around boreholes located approximately 40 ft southeast and 80 ft northeast of borehole 21-10-12, indicating the presence of a relatively extensive contaminant plume. At borehole 299-E33-46 (near tank B-110; Figure 27b), ^{90}Sr was identified in soil samples from the interval between an elevation of 611 ft and 574 ft (log depths of 46 to 83 ft), with ^{90}Sr values up to 11,250 pCi/g of sediment (Knepp 2002). On the basis of slightly higher NaI detector count rates, it is believed a relatively high radiation zone occurs down to 557 ft elevation (100 ft bgs). This zone is significant because of the probability that ^{90}Sr exists within this interval. A zone of anomalous gamma activity was observed between 587 and 575 ft elevation (70 and 82 ft bgs) around borehole 20-10-02, which is located approximately 40 ft southeast of borehole 20-10-12. No discernable full energy peaks were observed in the gamma-ray spectra. Similar anomalous zones have also been observed in boreholes 20-07-11 and 20-08-07, located about 80 ft east and northeast of borehole 20-10-12, respectively, at the same approximate depth but at apparently lower intensities. These anomalies are interpreted as evidence of possible bremsstrahlung radiation that are indicative of the presence of ^{90}Sr. Shape factor analysis results support the conclusion that ^{90}Sr exists around these boreholes (DOE 2000d). The apparent spatial continuity of these zones as encountered in boreholes 20-07-11, 20-08-07, 20-10-02, and 20-10-12 strongly suggests the presence of a relatively extensive contaminant plume, in which ^{90}Sr is likely the predominant radionuclide.

At borehole 299-E33-46, ^{99}Tc is present in a few soil samples in the Plio-Pleistocene Unit (Knepp 2002). The northeastern stratigraphic dip (Figures 26a, 26b, and Appendix B) of the sediments suggests that potential sources of the ^{99}Tc are located to the southwest of borehole 299-E33-46. The only known potential sources are tank B-110 and unplanned releases near the 241-B-151, -152, & -153 Diversion Boxes, which are located in the extreme southwestern portion of the B Tank Farm. On the basis of soil sample results from borehole 299-E33-46, Knepp (2002) concluded that ^{99}Tc releases into the vadose zone near tank B-110 appeared to be inconsequential. ^{99}Tc does not occur above detection limits in the upper portion of the vadose zone in borehole 299-E33-46, where other tank waste constituents (e.g., ^{90}Sr, fluoride, carbonate, and nitrate) are present. The Plio-Pleistocene Unit appears to be an effective conduit for lateral migration and the presence of ^{99}Tc is postulated to have a source other than tank B-110 (Knepp 2002). It is unlikely that ^{99}Tc comes from the tank B-110 waste source (Knepp 2002), because its concentration

distribution profile is incongruent with the nitrate profile (e.g., ^{99}Tc is found primarily in the Plio-Pleistocene and nitrate is found in both the Hanford formation and the Plio-Pleistocene with maximum values in the Hanford formation). However, due to the lateral spreading of wastes in the vadose zone, the location of borehole 299-E33-46 is probably too close to the spill at tank B-110 to fully evaluate this spill's impact on groundwater. A groundwater well drilled at a location between tanks B-106 and B-108 was needed to evaluate the impact of the spill near tank B-110 on groundwater.

5.3.2.3 BY Tank Farm

The spectral gamma log data show ^{137}Cs (Figures 20 and 21) is the most abundant radionuclide detected throughout the BY Tank Farm. ^{60}Co (Figures 24 and 25) was also detected in fairly extensive distributions, but in much lower concentrations than ^{137}Cs; ^{60}Co was often detected at the bottoms of boreholes. Other gamma-emitting radionuclides detected are ^{125}Sb, ^{154}Eu, and processed ^{238}U.

^{60}Co contamination was detected below every tank in BY Tank Farm that was designated as a leaker (Figures 24 and 25). Concentrations of ^{60}Co contamination were generally less than 10 pCi/g; however, both the depth extent and areal distribution of the ^{60}Co contamination were extensive. ^{60}Co contamination was often detected alone below the tank bases within the sediments of the Hanford H2, and the visualizations show extensive areal distribution of the ^{60}Co contamination relative to the ^{137}Cs contamination. The majority of the ^{60}Co contamination was detected in sediments of the Hanford H2. The 100-ft depth extent (~553 ft elevation) of many of the monitoring boreholes in the BY Tank Farm means that the maximum depth extent of the BY Tank Farm ^{60}Co contamination plumes is not known. Therefore, any impacts of the vadose zone contamination on the groundwater cannot be directly determined.

Surface areas of ^{137}Cs contamination with concentrations greater than 1,000 pCi/g were observed in several areas in the BY Tank Farm (Figure 30). The most intense areas were above tanks BY-101, BY-102, BY-104, BY-105, BY-107, and BY-108. Documented unplanned releases that occurred at tanks BY-107 and BY-112 were associated with problems with tank ancillary equipment and piping. ^{60}Co contamination along with ^{137}Cs contamination was detected at ground surface near tank BY-112 and is most likely associated with two documented releases of radiologically contaminated waste materials. Some of the high gamma-ray count rates detected at the surface may be from near-surface contamination in pipelines that traverse the BY Tank Farm in many locations. The pipelines are covered with gravel and/or soil material, but the gravel thickness may not be sufficient to attenuate all the gamma rays (DOE 1997a).

Tank BY-111 is designated sound (Hanlon 2003). An interval of low-level ^{60}Co contamination was detected in borehole 22-11-09 at elevations from 628 to 598 ft (25 to 55 ft bgs). Occurrence reports in 1975 and 1978 documented liquid-level decreases in tank BY-111, and Tank Farms gross gamma-ray logs acquired in borehole 22-11-09 during this time frame show increases in gamma-ray activities. It appears that this tank has leaked, and the designation of this tank should be changed to a leaker (DOE 1997a).

There is evidence of possible contaminant movement in the vadose zone under BY Tank Farm. Randall and Price (1998) identified 26 boreholes where contaminants have been unstable at some time between 1975 and 1994. Contaminants around nine of these boreholes (22-00-02, 22-06-05,

22-07-02, 22-07-05, 22-07-07, 22-08-02, 22-08-12, 22-10-07, and 22-11-01) continued to be unstable in 1994, when the gross gamma monitoring program was discontinued. The repeat logging data from boreholes 22-06-05 and 22-08-05 in 1999 suggest movement may be continuing, but could be due to a lateral influx of contaminants (DOE 2000c). This logging is somewhat contradictory to the results of the Randall and Price (1998) study, which suggested downward movement. Since June 2001, possible movement has been detected at boreholes 22-03-04, 22-07-02, and 22-07-05 in the BY Tank Farm (Table 3-3). It is likely in this farm as well as in others, that subtle changes cannot be confirmed in relatively short periods of time with the current monitoring system.

5.3.2.3.1 Groundwater Well 299-E33-9

^{137}Cs and ^{60}Co were detected in this borehole with the SGLS. ^{60}Co was detected in three distinct elevation intervals: from 477 to 460 ft (177 to 194 ft log depth) with a maximum concentration of 3 pCi/g, from 446 to 441 ft (208.5 to 213.5 ft log depth) with a maximum concentration of 0.3 pCi/g, and from 408 to 394 ft (246.5 to 260.5 ft log depth) with a maximum concentration of 2.5 pCi/g. Low levels (less than 2 pCi/g) of ^{137}Cs were detected throughout the entire borehole. ^{137}Cs concentrations near the ground surface were as high as 6,000 pCi/g. Other intervals of elevated ^{137}Cs occurred at 576 (78.0 ft log depth) with a concentration of 20 pCi/g, between 426 to 420 ft (228.0 and 234.0 ft log depth) where concentrations reached 150 pCi/g, and between 408 and 394 ft (246.5 and 260.5 ft log depth) where concentrations reached 20 pCi/g. Most of the ^{137}Cs is attributed to borehole effects except for that near the ground surface and below an elevation of 420 ft (228 ft log depth).

The ^{60}Co detected at elevations between 460 and 477 ft (177 to 194 ft log depth) in well 299-E33-9 underneath BY Tank Farm may be stratigraphically controlled by the fine-grained interval at comparable elevations in well 299-E33-44 (Figure 27a). The ^{60}Co in this interval correlates with the ^{60}Co in the interval at elevations between 475 and 470 ft (157 to 162 ft log depth) at well 299-E33-13 (Figure 29). A large ^{60}Co contamination plume (Figure 35) resulted from leakage from tank BY-103 that appears to spread in a southerly direction to connect with contamination at an elevation of 475 ft (179 ft log depth) at well 299-E33-9 (22-02-07) and is shown in the visualization (Figures 33 and 35). The source of this ^{60}Co is either from the BY Cribs, which are down dip from well 299-E33-9, or a source in BY Tank Farm such as tank BY-103.

Most of the ^{137}Cs is attributed to borehole effects except for that near the ground surface and below 422 ft in elevation (232.0 ft log depth). The near-surface ^{137}Cs is attributed to surface spills (DOE 2000c), and the ^{137}Cs below 409 ft in elevation (245.0 ft log depth) is attributed to contaminated groundwater that may have originated from sources outside the BY Tank Farm, such as the BY Cribs. According to DOE (2000c), the ^{137}Cs at an elevation of 422 ft (232 ft log depth) was not considered to be within the formation, because it was thought that contamination may have settled on top of a packer that had been set at this depth prior to grouting the annulus. Alternately, DOE (2000c) proposed that an artificially high water level caused by discharges to nearby liquid waste disposal sites may have mobilized the ^{137}Cs observed at 422 ft (232 ft log depth). The ^{137}Cs at an elevation of 422 ft is in the same stratigraphic interval as the deep ^{137}Cs observed at the nearest older (pre-1970) groundwater wells 299-E33-8 and 299-E33-13 (Figure 29) and the ^{238}U observed at well 299-E33-18 (Figure 27a).

At depth, the most significant accumulations of radionuclides appear within the Cold Creek Unit as discussed in Section 5.3.3. The ^{60}Co detected by the SGLS at well 299-E33-9 (Figure 29) represents

a deep remnant contaminant plume. The source of this deep ^{60}Co is probably the BY Cribs. The source of ^{137}Cs in well 299-E33-9 underneath BY Tank Farm in the interval between 426 to 420 ft in elevation (228 to 234-ft log depth) is not readily apparent, as there are no nearby deep ^{137}Cs vadose zone plumes.

This borehole was logged with a gross gamma tool by site personnel in 1959 and 1963. Subsequent gross gamma logging was performed between 1975 and 1994 by Tank Farms personnel, but only to a depth of 150 ft (504 ft elevation). Because routine gross gamma logging conducted between 1975 and 1994 only recorded data from the ground surface to 150 ft (504 ft elevation), the bottom portion of this borehole was not evaluated by Randall and Price (1998). Both this study and DOE (2000c) retrieved the gross gamma logs for 1959 and 1963 from PNNL files. These logs were examined for zones of possible deep contamination that could be correlated with zones identified during the SGLS logging. Both logs indicated gamma-emitting contaminants in the groundwater interval during 1959 and 1963. The 1959 log showed high count rates for a 10-ft interval from 232 ft (422 ft in elevation) to the recorded logging depth of 242 ft (412 ft in elevation). The 1963 log shows elevated gamma activity for a 17-ft interval from 248 ft (406 ft elevation) to the recorded logging depth of 265 ft (389-ft elevation). DOE (2000c) interpreted the high count rates at the log depth of 232 ft (422 ft in elevation) as the groundwater level in 1959 and the total logging depth of 242 ft as a logging depth error of approximately 20 ft. As developed in Section 5.3.3, perched water containing contaminants at 232 ft (422 ft in elevation) is another explanation for the high count rates at 232-ft log depth on the 1959 log.

The 1963 log showed zones of possible contamination from 150 to 181 ft (504 to 473 ft) and near 211 ft (elevation of 443 ft) that were not apparent in the 1959 log (DOE 2000c). The zone at 211 ft (elevation of 443 ft) and the elevated activity below the water level roughly correlate with the zones of ^{60}Co detected with the SGLS in 1999. The ^{60}Co detected in 1999 between about 177 and 192 ft (477 and 462 ft in elevation) is a thinner and deeper interval than the 1963 anomaly between 150 and 181 ft (504 to 473 ft elevation). The 1963 gross gamma log is shown on Figure 44, and the 1999 SGLS log is shown on Figure 29.

5.3.2.3.2 Tank BY-103

Tank BY-103 is designated an assumed leaker (Hanlon 2003). High gross gamma-ray count rates observed in borehole 22-00-03 in 1969 resulted in a questionable integrity designation for the tank. In 1971, leakage was confirmed when the contamination plume was detected in newly constructed borehole 22-03-05. The tank was declared a leaker in 1973 with a leak volume estimated to be less than 5,000 gal.

The most extensive contamination plume in terms of highest ^{137}Cs concentrations was measured in borehole 22-03-05 (299-E33-103) on the southeast side of tank BY-103, where concentrations were high enough to saturate the SGLS sonde between 627 and 607 ft elevation (25 and 45 ft log depth). The ^{137}Cs concentration within this interval exceeded 10 million pCi/g. ^{137}Cs and ^{60}Co concentrations were detected immediately below the high dead-time zone to a depth of 100 ft (552 ft elevation), which is the total depth of borehole 22-03-05 (299-E33-103). Low concentrations of ^{125}Sb (Figure 19) occur within this plume; this radionuclide was detected in several boreholes on the eastern side of tank BY-103. A large ^{60}Co contamination plume (Figures 33 and 35) resulted from leakage from tank BY-103 that appears to have spread in a southerly direction to connect with contamination at an elevation of 475 ft (179 ft log depth) in well 299-E33-9 (22-02-07). The

perspective of Figure 33 makes it appear that the ^{60}Co vadose zone plume is beneath the northern end of the 216-B-8 Tile field, but it does not actually extend beneath the tile field. The total depth and northeastern extent of the tank BY-103 vadose zone plume to the northeast of borehole 299-E33-84 (22-00-03) are not known because contamination was detected at the bottom of this borehole (Figure 29), and ^{60}Co was detected to the northeast at an elevation of 473 ft (159 ft log depth) in 299-E33-13 (Figure 29). The BY Cribs (Figure 35) are also a potential source of this ^{60}Co in well 299-E33-13.

The plume of ^{60}Co contamination under the west side of tank BY-103 may be related to the leakage from tank BY-103, or it may have originated from leakage from tank BY-106. Tank BY-106, which is adjacent to tank BY-103 to the west, is also a known leaker (Hanlon 2003).

5.3.2.3.3 Tank BY-107

An extensive plume of ^{60}Co contamination underlies tank BY-107 and is most likely related to leakage from the tank (DOE 1996g and 1997a). Operational activities may have caused increased moisture and subsequent redistribution of pre-existing contamination resulting in a complex ^{60}Co contamination distribution (DOE 1996g, 1997a). The most continuous distribution of this contamination begins slightly below the tank base; however, some occurrences of ^{60}Co were detected above the tank base. In borehole 22-07-02, ^{60}Co contamination is present near the ground surface (Figure 35). Jones et al. (2001) asserted that the spectral gamma logging data do not provide strong evidence of a leak from this tank and that the ^{60}Co at depths below the base of the tank percolated down from the ground surface. However, these assertions are inconsistent with the spectral gamma data as there isn't a nearly continuous profile of gamma-emitting radionuclides from the surface to the base of the tank, and the source of the ^{60}Co can not be tracked from below the base of the tank to the surface. Because tank BY-107 (299-E33-108 [22-04-09] on Figure 29) is located up stratigraphic dip from groundwater well 299-E33-9 (22-02-07), tank BY-107 is a potential source of the deep-seated ^{60}Co and ^{137}Cs detected in well 299-E33-9 (Figure 29).

Tank BY-107 was identified as a leaker in 1974 when a significant liquid-level decrease was measured in the tank (Hanlon 2003). Subsequent evaluation of the liquid loss estimated a leak volume of more than 15,000 gal. Concurrent with the decreased liquid level, an increase in the radiation intensity at 624 ft elevation (29 ft bgs) was measured in borehole 22-07-02 (299-E33-206) with the Tank Farms gross gamma-ray logging system. The liquid waste volume in the tank was immediately reduced, liquid-level readings stabilized, and the tank was considered stable at the reduced volume. Although borehole radiation intensities at first appeared to stabilize, they again increased. The increases were attributed to migration of old contamination present in the sediments. Details of the environmental conditions causing the apparent redistribution of the contamination are described in the Tank Summary Data Report for tank BY-107 (DOE 1996g).

5.3.3 Vadose Zone Contamination in the Cold Creek Unit

Spectral gamma logging of the 49 boreholes (Table 5-3) that penetrated the Cold Creek Unit detected radionuclides in 31 boreholes at depth. ^{137}Cs or ^{60}Co were detected in all 28 of the wells drilled before 1972 and none of the 21 wells drilled after 1972. The amounts of ^{60}Co and ^{137}Cs detected were generally less than 20 pCi/g and at depths just above and within the current groundwater level. The contamination is generally sporadic or non-existent in the upper vadose zone except in boreholes that are located within a contaminated waste site (Figures 20, 21, 24, and 25).

Most of these boreholes were drilled in the 1950s. Boreholes drilled after the 1970s (e.g., C3103 and 299-E33-41 through -46) do not exhibit any ^{137}Cs or ^{60}Co contamination in depth intervals near groundwater. Uranium contamination was detected in boreholes 299-E33-18 and -41 just above the groundwater. As discussed in Section 5.3.2.2, this uranium contamination is from the spill at tank BX-102 where SGLS logging detected high levels of ^{137}Cs at borehole 299-E33-27 in the upper portion of the Cold Creek Unit. Borehole 299-E33-27 is the most recent borehole drilled that detected ^{137}Cs in the Cold Creek Unit. On the basis of soil samples (Knepp 2002), ^{99}Tc was detected in the Cold Creek Unit at boreholes 299-E33-45 and 299-E33-46, which were drilled in 2001.

Rust has an affinity to concentrate radionuclides on the casing at Hanford. Brown and Ruppert (1950) compared the radioactivity of rust and groundwater samples and reported that "*weight for weight rust was 4400 times as active as the water*." Womack and Larsen (1971) tested a contaminated zone by raising the casing 10 ft in borehole 299-E33-61, taking a radiation profile, then the casing was lowered to its original position and another radiation profile was acquired. It was concluded from the results that a radioactive deposit of some sort is present on the casing.

The groundwater was significantly contaminated by 1956 from the BY Cribs (Thomas et al. 1956), and a perched zone may have existed below an elevation of approximately 431 ft (200 ft bgs). A perched water zone such as that encountered in borehole 299-E33-41(Narbutovskih 1998; Wood et al. 2000b) may have extended from 431 ft to groundwater (227 to 257 ft log depth). ^{137}Cs and ^{60}Co contamination may have been adsorbed to rust on the steel pipe. DOE (2002b, 2003a) postulated that as the perched water and groundwater receded over the years, a "bathtub ring" was formed on the casing, which resulted in apparent contamination above the current groundwater level. Therefore, the apparent contamination where it is not continuous from the upper vadose zone to the groundwater may be an artifact of an historical groundwater plume or perched water and not entirely representative of contamination distributed in the formation. The lack of contamination in the 13 RCRA-compliant wells, which were drilled after 1989, would support this hypothesis. However, these RCRA wells have a large annular space filled with material such as bentonite and sand that impede measurement of gamma rays from the formation by the SGLS. The highest historic groundwater level in the area is about 410 ft (Figure 5), which generally coincides with the top of an interval of ^{60}Co contamination in the older groundwater wells (Figure 29).

5.3.3.1 ^{60}Co Contamination near Groundwater Level

^{60}Co has a characteristic signature at the bottom of the older groundwater wells. The groundwater was significantly contaminated in the 1950s (Thomas et al. 1956), primarily from the BY Cribs north of the BY Tank Farm, some of the waste sites in the area, and possibly from tank wastes. The ^{60}Co contamination may have been adsorbed to rust on the steel casing. As the groundwater receded over the years a "bathtub ring" was formed on the casing, which resulted in apparent contamination near the current groundwater. Therefore, the apparent contamination is probably an artifact of an historical groundwater plume and not representative of contamination distributed in the formation.

^{60}Co is widely distributed at elevations near that of the current groundwater level (401 ft) as shown on Figures 24, 25, and 34. At these depths, ^{60}Co was detected only in the older wells. This ^{60}Co is shown in the BY Cribs in the north, to the 216-B-61 Crib and 216-B-42 Trench in the west, as far south as well 299-E28-8, and to well 299-E33-14 to the east (Figure 25 shows the isolated ^{60}Co spheres at the bottom of boreholes and Figure B-1 [Appendix B] shows the borehole locations). The

actual limits of this remnant ^{60}Co plume have not been determined, but it extends to the 216-B-5 Injection Well to the southeast (Smith 1980 and DOE 2002e). Except for near the BY Cribs, activities have now decayed to trace amounts (0.1 to 1 pCi/g) because of the relatively short half-life of ^{60}Co (about 5.2 years). Cross Sections A-A', B-B', C-C', and D-D' (Figures 26 through 29, respectively) depict the distribution of ^{60}Co in the subsurface. The ^{60}Co concentration is greater in the vicinity of the BY Cribs (e.g., approximately 10 pCi/g) where the contamination extends continuously from the upper vadose zone to groundwater (borehole 299-E33-1A, Figure 29).

The ^{60}Co from the BY Cribs broke through to groundwater (Thomas et al. 1956). ^{60}Co is detected in groundwater in the wells drilled before the 1970s. Figures 24, 25, and 33 indicate that the BY Cribs are the source of the deep ^{60}Co contamination. At the top of the Cold Creek Unit, the higher ^{60}Co concentrations are localized near the BY Cribs (Figure 45). The 100-ft depth extent (~553 ft elevation) of many of the monitoring boreholes in the BY Tank Farm prevents detection of vadose contamination that may be at greater depths or has originated from the BY Tank Farm. Contamination from the BY Cribs would be intersected much deeper (log depth) in boreholes in the BY Tank Farm because ground surface at the BY Tank Farm is about 40 ft higher than ground surface at the cribs. DOE (1993b) indicated that a radioactive front in groundwater reached well 299-E33-8 in 1968; however, the gross gamma logs published in Additon et al. (1978) indicate that groundwater was contaminated as early as May 1959. This radioactive front reached groundwater well 299-E33-10, near the 216-B-42 Trench, in 1976 (DOE 1993b). Near the 216-B-5 Injection Well, elevated gamma (interpreted as ^{60}Co) was observed below groundwater level in 1959 as far south as well 299-E28-1. Gross gamma logs from 1963 for wells 299-E28-2, 299-E28-5, and 299-E28-10 (Additon et al. 1978) also indicate elevated gamma below the groundwater level. Elevated gamma was not observed in well 299-E28-14 in 1968. The log collected on 5/4/76 detected gamma activity above background in well 299-E28-14. The elevated gamma in well 299-E28-14 indicates that a radioactive contaminant front passed through well 299-E28-14 between 1968 and 1976 (Smith 1980).

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
C3103 216-B-7A Crib	09/2001	None			Total gamma increase and perched water reported at TD[1] (435 ft elevation or 218 bgs).
C3104 216-B-38 Trench	08/2001	445- ^{137}Cs (218)	0.2	Fluctuation in counting statistics	No evidence of a photopeak at 661 keV.
299-E28-8 S of BX Tank Farm	09/1957	378, 377, & 371 - ^{60}Co (290, 291 & 297)	0.3	BY Cribs	Elevated gamma (interpreted as ^{60}Co) probably present in May 1963 below 290 ft log depth.

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
299-E33-1A 216-B-43 Crib	08/1954	Intermittent 430-398 - ^{137}Cs (205-237) 440-396 - ^{60}Co (195-239)	2 22	BY Cribs	^{60}Co continuous from upper vadose zone.
299-E33-2 216-B-44 Crib	10/1954	424-409 - ^{137}Cs (211-226) 440-391 - ^{60}Co (195-244)	< 1 15	BY Cribs	^{60}Co continuous from upper vadose zone.
299-E33-3 216-B-45 Crib	11/1954	Intermittent 414-411 - ^{137}Cs (220-223) 440-391 - ^{60}Co (194-243)	< 1 16	BY Cribs	^{60}Co continuous from upper vadose zone.
299-E33-4 216-B-46 Crib	12/1954	440-400 - ^{60}Co (193-233)	21	BY Cribs	^{60}Co continuous from upper vadose zone.
299-E33-5 216-B-47 Crib	06/1955	426-421 - ^{137}Cs (213-218) 413-409 - ^{137}Cs (226-230) 407-396 - ^{60}Co (232-243)	4 2 6	BY Cribs	^{60}Co not continuous from upper vadose zone. Elevated gamma (interpreted as perched water containing ^{137}Cs) present at 429 ft (210 ft log depth) in 1959.
299-E33-6 216-B-49 Crib	06/1955	416-402 - ^{137}Cs (212-226) 405-390 - ^{60}Co (223-238)	2 3	BY Cribs	^{60}Co not continuous from upper vadose zone. Elevated gamma (interpreted as perched water containing ^{137}Cs) present at 425 ft (203 ft log depth) in 1959.
299-E33-7 216-B-50 Crib	04/1955	440-427 - ^{137}Cs (191-204) 419-410 - ^{137}Cs (212-221) 440-397 - ^{60}Co (191-234)	2 4 11	BY Cribs	^{60}Co continuous from upper vadose zone. Elevated gamma (interpreted as perched water containing ^{137}Cs) present at 431 ft (200 ft log depth) in 1959.
299-E33-8 NE of 216-B-41 Trench	10/1953	427-404 - ^{137}Cs (227-250) 403-396 - ^{60}Co (251-258)	3.5 0.3	BY Cribs	Elevated gamma (interpreted as perched water containing ^{137}Cs) present at 428 ft (226 ft log depth) in 1959.

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
299-E33-9 SW of Tank BY-102	07/1949	445 - ^{60}Co (209) 425-420 - ^{137}Cs (229-234) 410-394 - ^{137}Cs (244-260) 408-394 - ^{60}Co (246-260)	0.2 150 20 2.3	BY Cribs, or tanks BY-103, BY-107 or BY-108	Elevated gamma (interpreted as perched water containing ^{137}Cs) present at 419 ft (235 ft log depth) in 1959.
299-E33-10 SW of 216-B-42 Trench	04/1955	410-409 - ^{137}Cs (267-268) 400, 396 - ^{60}Co (277, 281)	0.3 0.2	BY Cribs and 216-B-36 & -37 Trenches	Elevated gamma in the interval from 425 to 415 ft in 1970. Elevated gamma (interpreted as ^{60}Co) present near groundwater in 1976.
299-E33-11 E of 216-B-51 French Drain	01/1954	410-409 - ^{137}Cs 409-396 - ^{60}Co	< 1 8	BY Cribs	Elevated gamma (interpreted as perched water) present at 426 ft in 1959.
299-E33-12 E of BY Cribs	09/1953	409-391 - ^{60}Co (218-236) Intermittent 372-302 - ^{60}Co (255-325)	6 < 1	BY Cribs	Contamination extends into the basalt.
299-E33-13 NE of Tank BY-103	10/1953	427-403 - ^{137}Cs (205-229) 397-396 - ^{137}Cs (235-236) 413-396 - ^{60}Co (219-236)	18 8 8	BY Cribs	Tank BY-103 may be source of ^{60}Co detected in the upper vadose zone. Elevated gamma (interpreted as perched water containing ^{137}Cs) present at 428 ft in 1959.
299-E33-14 NE of 216-B-8 Tile Field	12/1953	412-411 - ^{137}Cs (213-214) 411-395 - ^{60}Co (214-230)	< 1 4	BY Cribs	Elevated gamma (interpreted as perched water) present at 425 ft in 1959.
299-E33-15 216-B-8 Tile Field	02/1953	409-407 - ^{137}Cs (222-224) 409-391 - ^{60}Co (222-240)	< 1 12	216-B-8 Crib and BY Cribs	Elevated gamma (interpreted as perched water containing) present at 427 ft in 1959.
299-E33-16 216-B-8 Crib	01/1953	425-419 - ^{60}Co (217-223) 404-389 - ^{60}Co (238-253)	< 1 6	216-B-8 Crib and BY Cribs	Elevated gamma (interpreted as perched water containing ^{60}Co) present at 429 ft in 1959.

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
299-E33-17 E of 216-B-8 Crib	10/1953	416-407 - ^{137}Cs (219-228) 409-392 - ^{60}Co (226-243)	2 11	BY Cribs	
299-E33-18 SW of 216-B-7B Crib	02/1950	421-401 - $^{235/238}$U (234-254) 422-410 - ^{60}Co (235-245) 403-394 - ^{60}Co (252-261)	50/600 2 < 1	Tank BX-102 source for 1990's influx of uranium. BY Cribs source of ^{60}Co below 403 ft	Elevated gamma at 461 ft in 1959. Elevated gamma (interpreted as perched water containing ^{60}Co) present at 428 ft in 1959.
299-E33-19 216-B-11B French Drain	06/1956	421-406 - ^{137}Cs (233-248) 424-420 - ^{60}Co (230-234) 408-405 - ^{60}Co (246-249)	3 < 1 < 1	216-B-11A & B French Drains and BY Cribs	This French drain is a 2-ft-diameter 30-ft-vertical culvert to a depth of 40 ft (612 ft elevation).
299-E33-20 216-B-11A French Drain	07/1956	410-407 - ^{137}Cs (240-243) 405-402 - ^{60}Co (245-248)	2 < 1	216-B-11A & -11B French Drains and BY Cribs	This French drain is a 2-ft-diameter 30-ft-vertical culvert to a depth of 40 ft (608 ft elevation).
299-E33-21 216-B-36 Trench	02/1957	450-412 - ^{137}Cs (222-260) Intermittent 406-387 - ^{137}Cs (266-285) 394-392 - ^{60}Co (278-280)	1 46 0.6	216-B-36 & -37 Trenches and BY Cribs	Groundwater contaminated in 1957. Depth registration error on 1957 gross gamma log.
299-E33-22 216-B-45 Crib	08/1965	440-399 - ^{137}Cs (194-235) 431-399 - ^{60}Co (203-235)	21,000 10	216-B-45 Crib	^{60}Co probably and ^{137}Cs continuous from upper vadose zone.
299-E33-23 216-B-46 Crib	09/1965	440-400 - ^{137}Cs (193-233) 440-400 - ^{60}Co (193-233)	9 10	216-B-46 Crib	^{60}Co and ^{137}Cs continuous from upper vadose zone.
299-E33-24 216-B-57 Crib	05/1967	437-410 - ^{137}Cs (204-231) 413-395 - ^{60}Co (228-246)	< 1 5	BY Cribs	Elevated gamma present in 1968 below 405 ft.

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
299-E33-25 216-B-61 Crib	02/1969	426, 418, 414 - ^{137}Cs (208, 216, 220) 410-402 – ^{60}Co (224-232)	< 1 < 1	BY Cribs	The 216-B-61 Crib was never used. Elevated gamma present in 1970 below 404 ft.
299-E33-26 216-B-61 Crib	03/1969	431 & 409 - ^{137}Cs (205 & 227) 403-397 -^{60}C (233-239)o	< 1 2	BY Cribs	The 216-B-61 Crib was never used. Elevated gamma present in 1970 below 403 ft.
299-E33-27 (22-02-04) Tank BX-102	07/1970	440-429 - ^{137}Cs (220-231)	100,000	Tank BX-102	Well no longer intercepts groundwater.
299-E33-31 West of BY Tank Farm	09/1989	None			Logged with RLS.
299-E33-32 West of BX Tank Farm	09/1989	None			Logged with RLS.
299-E33-38 216-B-47 Crib	02/1991	440-430 - ^{60}Co (195-205)	1	BY Cribs	^{60}Co not near groundwater.
299-E33-39 NE of 216-B-51 French Drain	02/1991	None			
299-E33-40 NW of 216-B-50 Crib	04/1991	440-430 - ^{60}Co (188-198)	< 1	BY Cribs	^{60}Co not near groundwater.
299-E33-41 NE of Tank BX-102	03/1991	Intermittent 580-411 - $^{235/238}$U (78-247)	40/700	Tank BX-102	Perched water below an elevation of 431 ft (224 ft bgs) when drilled (Narbutovskih 1998).
299-E33-42 SW of BY Farm	11/1991	None			Logged with RLS.
299-E33-43 W of BX Tank Farm	11/1991	None			Logged with RLS.
299-E33-44 E of BY Tank Farm	09/1998	None			Logged in 1998 with (NaI) system borehole not logged below 135-ft log depth with SGLS in 2002.
299-E33-45 E of Tank BX-102	01/2001	438-418 - ^{99}Tc (200-220)	20 pCi/g (PNNL 2002b)	Tank BX-102	Perched water between 431-426 ft (227-232 ft bgs; PNNL 2002b).

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
299-E33-46 Tank B-110	06/2001	435-431 - ^{99}Tc (222-226)	89,800 pCi/L (PNNL 2002c)	Unknown	Between 437 and 431 ft (220 and 226 ft bgs) "is the wettest material in the borehole" (PNNL 2002c).
299-E33-296 216-B-44 Crib	03/1992	Intermittent 440-414 - ^{137}Cs (192-218) 440-407 - ^{60}Co (192-225) 440-407 - ^{99}Tc (192-225)	< 1 < 1 140	BY Cribs	^{60}Co continuous from upper vadose zone.
299-E33-302 216-B-49 Crib	01/1992	Intermittent 440-418 - ^{137}Cs (189-211) 440-408 - ^{60}Co (189-221) 440-408 - ^{99}Tc (189-221)	< 1 < 1 140	BY Cribs	^{60}Co continuous from upper vadose zone; ^{99}Tc probably continuous (DOE 1993b). Borehole abandoned.
299-E33-304 216-B-57 Crib	10/1991	Intermittent 435-419 - ^{137}Cs (205-221) Intermittent 417-411 - ^{60}Co (223-229) 405 - ^{99}Tc (235)	< 1 < 1 < 1	216-B-57 Crib	^{60}Co not continuous from upper vadose zone; ^{99}Tc at bottom of borehole (DOE 1993b). Borehole abandoned.
299-E33-334 SW of BX Tank Farm	01/2000	None			Perched water not reported (Horton 2000). Logged with RLS.
299-E33-335 S of BX Tank Farm	02/2000	None			Perched water not reported (Horton 2000). Logged with RLS.
299-E33-337 S of B Tank Farm	08/2001	None			Perched water not reported (Horton 2002).
299-E33-338 SE of B Tank Farm	08/2001	None			Perched water 435-440 ft (212-217 ft bgs) (Horton 2002).

Table 5-3. Deep Boreholes Logged with the SGLS

Borehole/ Groundwater Well Number & Location	Date Drilled	Interval (Elevation in ft) of Vadose Zone Contamination in the Cold Creek Unit (Log Depth in ft)	Maximum Concentration (pCi/g)	Interpreted Source	Comment
299-E33-339 SE of BX Tank Farm	08/2001	None			Perched water not reported (Horton 2002).

[1] TD – total depth

5.3.3.2 ^{137}Cs Contamination Just Above Groundwater Level

^{137}Cs (Figure 46) exists in many of the pre-1972 boreholes near the B-BX-BY WMA at elevations below 432 ft (~200 ft bgs), and this deep-seated ^{137}Cs is probably a remnant of ^{137}Cs in a perched water zone and groundwater. Although it is not observed in all boreholes (Table 5-2), 299-E33-27, -17, and -14 (Cross Section A-A'), -26 and -9 (Cross Section B-B'), -10 and -21 (Cross Section C-C'), -8, -9, -13 and -1 (Cross Section D-D') indicate ^{137}Cs below this depth. This "bathtub ring" effect has been observed in logs in pre-1972 deep boreholes at the 216-B-35 to -42 Trenches (DOE 2002a), 216-B-8 Crib and adjacent sites (DOE 2002b), and the 216-B-43 to -50, -57, and -61 Cribs (DOE 2003a) at most of the pre-1972 deep boreholes. ^{137}Cs has been detected in the Cold Creek Unit underneath the B-BX-BY WMA at boreholes 299-E33-27 (Figure 26a) and at 299-E33-9 (Figures 27a and 29).

Elevated gamma readings were present at depth (within the Cold Creek Unit) in 1959 and 1963 as indicated by gross gamma logs presented in Additon et al. (1978) and Raymond and McGhan (1964). These elevated gamma readings were interpreted as groundwater that had been contaminated by gamma-emitting radionuclides. Recently, the differences in apparent groundwater levels between the 1959 and 1963 gross gamma logs have been interpreted as depth errors (DOE 2000c, 2002a, and 2002b). On the basis of gross gamma logs from 1959, it is postulated a perched water zone may have developed from waste disposal in the BY Cribs to a maximum elevation of approximately 432 ft (~200 ft bgs) over an extensive area by 1959. Gross gamma logs from 1959 indicate that elevated gamma readings were encountered in almost all of the groundwater wells in the area at elevations as high as 432 ft (Table 5-3), which is approximately 22 ft higher than the highest water level of 410 ft in the area (Figure 5). These 1959 elevated gamma readings in the Cold Creek Unit from the late 1950s indicate the presence of radionuclides (such as ^{137}Cs and ^{60}Co) in the deep vadose zone well above the highest groundwater level that could only have been emplaced by perched water. By 1963, gross gamma logs presented in Additon et al. (1978) and Raymond and McGhan (1964) suggested that the perched water had dissipated and apparent groundwater levels were below 410 ft.

The potential sources of the ^{137}Cs in the Cold Creek Unit are the BY Cribs, the 216-B-37 Trench, and tank leaks. Thomas et al. (1956) attributed ^{137}Cs in groundwater to discharges to the BY Cribs. SGLS logging indicates ^{137}Cs in the vadose zone from the cribs to groundwater near the 216-B-45, -46, and -50 Cribs (Figures 20 and 21). The 1970 investigation of the tank BX-102 leak (Womack and Larkin 1971) detected ^{137}Cs in groundwater after drilling well 299-E33-27. Womack and Larkin (1971) attributed the ^{137}Cs in groundwater to dragdown during the drilling of well 299-E33-27. The

highest ^{137}Cs concentrations detected in the Cold Creek Unit are at well 299-E33-27 (Figure 46). Because ^{137}Cs was not encountered down dip in nearby deep boreholes 299-E33-41 and -45, the extent of the ^{137}Cs near borehole 299-E33-27 (21-02-04) is limited. The source of the ^{137}Cs encountered underneath the BY Tank Farm at well 299-E33-9 (Figure 29) is probably not the leaks at tanks BY-103, -107, and -108 because relatively high concentrations of ^{137}Cs were not detected below the bases of these tanks. Radionuclides from the 216-B-37 Trench may have broken through to groundwater (DOE 2002a). Data acquired from well 299-E33-21 (Figure 28a) show ^{137}Cs over the entire length of the borehole, and its location up dip (Figure 2) of wells 299-E33-8 and -9 (Figure 29) indicates that the 216-B-37 Trench is a potential source of the ^{137}Cs detected at wells 299-E33-8 and -9. The 216-B-37 Trench received an estimated 66,400 Curies (Ci) of ^{137}Cs versus 7,500 Ci of ^{137}Cs received by the BY Cribs (Simpson et al. 2001). It is documented that ^{60}Co and ^{137}Cs from the BY Cribs reached groundwater (Thomas et al. 1956), and the log data indicate that the vadose zone at the BY Cribs contains a substantial inventory of ^{137}Cs (Figure 31). As discussed in the previous section, ^{60}Co discharged at the BY Cribs reached groundwater and spread under the entire B-BX-BY WMA. The BY Cribs are probably the source of a majority of the remnant ^{137}Cs in the Cold Creek detected in the older groundwater wells.

5.4 Potential Uncertainties and Inaccuracies

The interpretations discussed above are subject to a relatively high degree of uncertainty because of the number and distribution of boreholes with respect to the waste sites; consequently, the horizontal and vertical extents of the vadose zone contamination are poorly controlled.

The construction of most boreholes is documented in the form of drilling logs. Most of the drilling logs provide varying degrees of detail regarding the drilling operations, geologic descriptions of sediments penetrated by the drilling, radioactivity encountered during drilling, and a description of the "as-built" configurations. Geologic descriptions are subjective and the depth control can vary by as much as 5 ft. The drilling logs provide information regarding when and how the boreholes were drilled and document the occurrences of radiological contamination that were encountered during drilling.

Some gamma-emitting radionuclides have shown an affinity to adsorb to rust on borehole casings, and the actual concentration of the radionuclide within the formation would be overestimated in this case.

6.0 Conclusions

Four groundwater wells were logged with the SGLS in the area south of the B-BX-BY WMA and integrated with existing RLS data from 7 boreholes and existing SGLS data from 273 boreholes in the B-BX-BY WMA and adjacent waste sites. Gamma-emitting radionuclide concentration data were collected for naturally occurring and man-made radionuclides. A review of historical information was conducted to integrate with current information when interpreting the data. ^{125}Sb, ^{137}Cs, ^{60}Co, ^{235}U, ^{238}U, ^{152}Eu, and ^{154}Eu were detected while logging, and empirical ^{137}Cs, ^{60}Co, and $^{235/238}$U contamination distribution models were created based upon the more than 70,000 stationary measurements acquired in the area containing the B-BX-BY WMA and adjacent waste sites. Data collected between 1995 and 2000 for the tank farms baseline characterization are incorporated with the current characterization data to evaluate the relationships of contamination and stratigraphy. Cross sections and models are used to create visualizations of the contamination distribution that are

discussed in this report. The information relating to the contamination distribution beneath the study area can be used to locate additional characterization boreholes, implement a monitoring program, to provide input for risk assessment calculations, and for planning site environmental activities.

^{125}Sb, ^{137}Cs, ^{60}Co, ^{152}Eu, ^{154}Eu, ^{235}U, and ^{238}U were detected while logging in this study area. ^{125}Sb (Figure 19) was detected near tanks BX-101, BX-102 (BX Tank Farm), and BY-103 (BY Tank Farm), as well as, near the 216-B-41 Trench and the BY Cribs. Maximum concentrations do not exceed 10 pCi/g. ^{137}Cs (Figures 20 and 21) was detected in the vadose zone at all of the waste sites and tank farms in the study area. Maximum concentrations exceed 20 million pCi/g near tanks BX-102 (299-E33-27) and BX-110 (299-E33-223). Concentrations of ^{137}Cs greater than 1 million pCi/g are limited to elevations above 525 ft msl or above log depths of approximately 135 ft underneath the tank farms and the BY Cribs. ^{137}Cs concentrations are less than 200,000 pCi/g underneath the remaining waste sites in the study area. Other than the BY Cribs and BY Tank Farm, ^{60}Co was usually detected below the base of a waste site or tank and confined to the upper vadose zone. At the BY Cribs, ^{60}Co was encountered from the base of the cribs to groundwater (Figures 24 and 25). ^{60}Co was detected near the ground surface in the BY Tank Farm. ^{60}Co was usually detected with ^{137}Cs above a log depth of 60 ft (~590 ft msl), and generally alone deeper in the subsurface. Isolated occurrences of ^{60}Co were encountered in the intervals at elevations of 477 to 462 ft (177 to 192 ft log depth) and 445 to 443 ft (209 to 211 ft log depth) in well 299-E33-9 and at elevations of 475 to 470 ft (157 to 162 ft log depth) in well 299-E33-13 (Figure 24).

^{154}Eu was detected in all three of the tank farms, the 216-B-7A Crib, and the BY Cribs. ^{154}Eu was detected in 21 boreholes (Figure 23) at elevations between 661 and 546 ft (~0 to ~105 ft log depth). The highest concentration encountered was127 pCi/g in borehole 299-E33-144 at an elevation of 632 ft (28 ft log depth) near tank BX-101. The distribution of ^{152}Eu in the vadose zone is similar to that of ^{154}Eu. The ^{152}Eu contamination generally occurs at much lower concentrations than the ^{154}Eu within the vadose zone sediments and may fall below its MDL when associated with low concentrations of ^{154}Eu.

Only 17 of 284 boreholes (Figure 22) encountered processed uranium (^{235}U and ^{238}U). ^{235}U concentrations are generally an order of magnitude less than ^{238}U concentrations. The most extensive area of $^{235/238}$U contamination is located northeast of tank BX-102. Thirteen of the 17 boreholes where processed uranium was detected are located in this area. ^{238}U concentrations as high as 1,000 pCi/g were detected east of tank BX-102 in boreholes 299-E33-134 and 299-E33-146. Processed uranium was detected in borehole 299-E33-165, southeast of tank BX-106, at elevations between 613 and 599 ft (45 to 59 ft log depth) and at concentrations reaching 200 pCi/g. Borehole 299-E33-18, located approximately 80 ft west of the 216-B-7A&B Cribs, exhibited $^{235/238}$U contamination between elevations of 421 and 401 ft (234 to 254 ft log depth) at concentrations exceeding 500 pCi/g for ^{238}U; groundwater elevation is at 401 ft in this area. Near the 216-B-7B Crib at borehole 299-E33-59, $^{235/238}$U was detected between elevations of 612 and 600 ft (42 to 54 ft log depth) at concentrations of 32 pCi/g for ^{238}U. Processed uranium (^{238}U only) was detected in borehole 299-E33-256 southwest of tank BY-111 at elevations between 591 and 590 ft (62 to 63 ft log depth) at concentrations reaching 26 pCi/g. Soil samples (DOE 1993b and 2003b) collected in the BY Cribs, 216-B-38 Trench (borehole C3104), 216-B-57 Crib, and 216-B-7A Crib (borehole C3103) indicate that uranium above background levels (0.3 to 1.5 pCi/g) is present only in the upper vadose zone (above an elevation of 600 ft or ~60 ft bgs). These elevated levels of ^{238}U (~100 pCi/g) occur in the zones of very high gamma flux due to concentrations of ^{137}Cs in excess of 1,000 pCi/g.

Because of the very high gamma flux caused by ^{137}Cs, uranium and other isotopes cannot be measured by the SGLS in these intervals. Below the high-activity zones, ^{238}U above background concentrations was not detected by spectral gamma logging in the vadose zone or reported in the available soil samples (DOE 2003b).

Log data acquired in two groundwater wells (299-E33-18 and -41) located northeast of tank BX-102 and outside the BX Tank Farm showed an influx of uranium contamination between 1991 and 1997. Uranium concentrations apparently continued to increase between 1997 and 2002 in well 299-E33-18 (DOE 2002b). In 2002, processed uranium was detected just above groundwater in the elevations between 421 and 401 ft (234 and 254 ft log depth) with a maximum concentration of 600 pCi/g. The 1992 RLS log did not detect processed uranium. Well 299-E33-18 is located near the 216-B-7A&B Cribs and is also 240 ft east-northeast of borehole 299-E33-41, which is located 140 ft from tank BX-102. Uranium concentrations in groundwater well 299-E33-41 increased from 200 to 1,000 pCi/g between 1991 and 1997 (Price 1998). This influx of uranium contamination (DOE 2002b) occurred in the interval between the elevations of 580 to 411 ft (log depths of 78 and 247 ft).

Between 1994 and 2002, an extensive southeast-northwest-trending uranium groundwater plume developed in the B-BX-BY WMA. In 1994, uranium concentrations above the MCL were reported in only two wells (299-E33-13 and -18). Uranium concentrations measured in groundwater wells in the vicinity of the B-BX-BY WMA indicate that the highest levels of uranium were observed in well 299-E33-18 in January 1994. By 1997, the highest reported uranium concentrations in the area were detected in well 299-E33-13. Uranium had also increased in concentration in well 299-E33-41 by March 1998. Conditions in 2000 (Figure 10), as reported by PNNL (2003), indicate that the uranium groundwater plume has grown to 2,500 ft in length.

The documented spill of 22.5 tons of uranium at tank BX-102 as described in GE (1951) is the source of the uranium contamination in the groundwater. The spill of processed uranium originated near the 4 o'clock position of the tank (borehole 299-E33-27) and has traveled to the northeast through the vadose zone. On the basis of relatively dense well control, the spill can be tracked as far as borehole 299-E33-41. Uranium migration is following the northeast stratigraphic dip in this area. Northeast of borehole 299-E33-41, the source of the processed uranium detected in borehole 299-E33-18 is probably the tank spill because it is located down dip of borehole 299-E33-41 and up dip of the nearby waste sites (i.e., 216-B-7A&B Cribs), where only a small amount of ^{238}U has been detected above an elevation of 600 ft (~60 ft bgs). The uranium contamination at well 299-E33-18 is at a lateral distance of 400 ft from its presumed source near tank BX-102. This uranium contamination near groundwater apparently reached boreholes 299-E33-41 and -18 between 1991 and 1997. Once uranium reaches the perched water within the Cold Creek Interval, it can be transported laterally over relatively large distances. The high moisture identified at the bottom of borehole C3103 may be related to the deep moisture zone identified in borehole 299-E33-41 and may contain uranium contamination. The groundwater uranium plume appears to originate northeast of well 299-E33-41 and near wells 299-E33-18 and -44. During the 1994 through 2002 period, uranium concentrations in groundwater have increased, and the uranium groundwater plume has expanded to the northwest. Uranium in groundwater has moved northwest and probably reached groundwater underneath the 216-B-61 Crib. SGLS logging in the study area has eliminated other tanks and waste sites as potential sources of uranium contamination in groundwater. The spill at tank BX-102 is the only credible source of the uranium groundwater plume, and the apparent groundwater flow direction over the last eight years has been to the northwest. A recently completed

remedial investigation report (DOE 2003b) for the waste sites adjacent to the WMA suggested that these waste sites are not the source of the uranium observed in the groundwater. These sites were the 216-B-46 Crib, 216-B-38 Trench, 216-B-57 Crib, and 216-B-7A Crib.

The WMA field investigation report (Knepp 2002) implied that the nearby waste sites are the source of the current uranium groundwater contamination. The differences in the extent and impact of the BX-102 uranium vadose zone plume as evaluated by Knepp (2002) and this report occur because this report includes SGLS results from both inside and outside the B-BX-BY WMA boundary, while Knepp (2002) does not include geophysical data from boreholes 299-E33-45 and 299-E33-41. By excluding the log results from boreholes 299-E33-45 and 299-E33-41, both the vertical and lateral extents of the uranium contamination as evaluated by Knepp (2002) are underestimated, as are the subsequent environmental impacts.

^{137}Cs and ^{60}Co contamination were detected in all deep boreholes drilled prior to the 1950s at depths consistent with the Cold Creek Unit. Boreholes drilled to the groundwater in the area since the mid 1970s did not exhibit any contamination. Although this may be related to differences in well construction, the contamination is postulated to be derived from perched groundwater contamination and groundwater contamination present in the 1950s. The contamination observed by the SGLS may have been adsorbed by rust and scale on the casing and may not represent contamination in the formation. The source of the majority of the historical ^{137}Cs contamination is probably the BY Cribs. Other wastes sites that may also have contributed ^{137}Cs to the deep vadose zone are the 216-B-36 and -37 Trenches and the 216-B-8 Crib. Data acquired from boreholes located near tanks BX-102, BX-107, and BX-110 exhibit high levels of ^{137}Cs and the related tanks may also be potential sources of ^{137}Cs contamination. One source of the historical ^{60}Co contamination is the BY Cribs. The BY Tank Farm may also be a potential source of the contamination, but the limiting 100-ft depth (~553 ft elevation) of the majority of boreholes in the BY Tank Farm biases the visualizations to indicate that the BY Cribs are the source.

^{137}Cs and ^{60}Co detected near the groundwater/vadose zone interface are largely the result of groundwater contamination from the BY Cribs prior to 1959. There generally is not a continuous record of contamination from high concentration zones above 150-ft log depth (~500 ft elevation) to the deep vadose zone. Waste from individual sites may have entered the groundwater at some time in the past as indicated in Table 5-1; however, the current geophysical log data cannot document a direct connection between a disposal site and groundwater except for the cases of processed uranium from tank BX-102 and the ^{60}Co originating from the BY Cribs. The wastes from the BY Cribs appear to have spread laterally and commingled. A remnant ^{60}Co plume (Figure 34) is encountered near groundwater, and Figure 35 is a visualization of the ^{60}Co distribution in the vadose zone with the remnant ^{60}Co plume removed. A composite of ^{137}Cs, ^{60}Co, and ^{238}U vadose zone plumes in the B-BX-BY WMA and adjacent waste sites is shown on Figure 36.

A comparison of the visualizations (Figures 30, 31, 32, 33, 35, and 36) indicates the impacts to the vadose zone of the farms and waste sites in the study area. The most extensive near-surface contamination (Figure 30) is ^{137}Cs detected in the BY Tank Farm. The 216-B-8 Crib and Tile Field is another area with ^{137}Cs contamination at the ground surface (Figure 30). The apparent ^{137}Cs vadose plumes are larger underneath the waste sites rather than below the tank farms (Figure 31). The largest ^{137}Cs plume is underneath the BX Trenches followed by the BY Cribs (Figure 31). Because not all of the BX Trenches have been characterized, the ^{137}Cs plume shown on Figure 31 underneath the BX Trenches does not extend far enough to the north and west to fully display the

extent of the ^{137}Cs contamination. Other relatively large ^{137}Cs vadose zone plumes (Figure 31) are located underneath the BY Cribs and the 216-B-8 Crib and Tile Field. A low-level ^{60}Co vadose zone plume (Figure 33) is present in the vadose zone underneath the BY Cribs that extends from the base of the cribs to groundwater. Soil samples collected in 1991 during the 200-BP-1 investigation (DOE 1993b) indicate ^{99}Tc and ^{60}Co extend to the groundwater below the BY Cribs. The contamination from the BY Cribs has also spread laterally. Based on the SGLS logging, all of the BY Cribs appear to have received similar waste streams, and characterization results collected at the 216-B-46 Crib (DOE 2003b) are applicable under the analogous site concept (DOE 1999a) to the all of the BY Cribs. Currently, the 216-B-50 Crib is grouped with the 200-PW-5 Operable Unit; however, SGLS results there are consistent with nearby Cribs that are in the 200-TW-1 Operable Unit. The full extent of the ^{60}Co contamination underneath the BY Tank Farm is unknown, and ^{60}Co from tank BY-103 may have spread laterally to reach wells 299-E33-9 and -13 (Figure 35).

SGLS logging results indicate that a comparison of the profiles of historical gross gamma logs and current SGLS logs, as well as, a more direct comparison of more recent RLS spectral logs with the SGLS, suggest ^{137}Cs contamination profiles and concentrations at the waste sites are relatively stable over time, while ^{60}Co and ^{238}U are more variable. Although questions remain about the true nature and extent of the ^{125}Sb, ^{137}Cs, ^{60}Co, europium, and uranium contamination, a baseline has been established for the study area. Future monitoring can be conducted to determine if the contamination is moving, where the contamination is going, and if additional sources are present.

Variations in natural radionuclides can be used to identify major changes in lithology. The H1 gravel-dominated facies is identified by a relatively low ^{40}K concentration of about 13 pCi/g and lower total gamma reading. The H2 sand facies is identified by a marked increase in apparent ^{40}K concentrations to about 18 pCi/g and an increase in total gamma count rate. In geophysical terms, the top of the Cold Creek Unit is defined as a zone of elevated total gamma count rate just above the point where apparent ^{40}K concentrations start to decrease. The Cold Creek Unit contains both fine-grained and coarse-grained sediments. It is identified by the presence of a silty-sand to silt layer that overlies coarse-grained sediments with a lower total gamma count rates and ^{40}K concentrations ranging from 12 to 15 pCi/g. Locally correlatable fine-grained layers may exist within each of the Hanford facies associations and the Cold Creek Unit.

SGLS log results are not consistent with the Hanford Soil Inventory Model (Simpson et al. 2001) estimates for uranium and ^{60}Co releases to the vadose zone. The Hanford Soil Inventory Model (Simpson et al. 2001) did not estimate releases in the BY Tank Farm, the 215-B-57 Crib, and the 216-B-50 Crib. According to the Hanford Soil Inventory Model (Simpson et al. 2001), the largest single release of uranium is from tank BX-102, which is consistent with the SGLS results. Substantial inventories (Figure 43) of uranium are predicted by the model for the BX Trenches, 216-B-7A&B Cribs, the BY Cribs, and the 216-B-8 Crib and Tile Field. The SGLS detected a minor amount of processed uranium only near the 216-B-7B Crib. Uranium was not detected in the vadose zone by any spectral gamma logging, while soil samples (DOE 1993b and 2003b) show total uranium above background concentrations only in high ^{137}Cs concentration zones just below the base of the waste sites. These results are more consistent with the GE (1951), Haney and Honstead (1958), Fecht et al. (1977) inventory estimates listed in Table 5-2. In Simpson et al. (2001), a comparison was made between a calculated soil data inventory and soil inventory model estimates for the BY Cribs. For the BY Cribs, the soil inventory model derived estimates were too high, usually by about an order of magnitude (Table 5-2). SGLS logging indicates that the majority of the

^{60}Co contamination in the vadose zone is associated with the BY Cribs, and, to a lesser extent, the BY Tank Farm (Figure 24). Simpson et al. (2001) indicated that the greatest releases of ^{60}Co occurred at the B Tank Farm (Figure 43), where a cumulative 2.7 Ci of ^{60}Co were lost to the vadose zone and that only 0.0014 Ci of ^{60}Co were discharged to the vadose zone at the BY Cribs. The current estimate of ^{60}Co releases for the BY Cribs appears to be too low.

7.0 Recommendations

Additional work is recommended to collect, catalog, digitize, assess, and analyze historical gross gamma logging results for this area. Historical logging performed in this area is poorly documented. Some work on collecting historical logs has been performed and presented in various publications that present only a fraction of the logs and are usually little more than a collection of logs with limited analysis results. Embedded in the historic logging is a record of individual contaminant plumes that can be used to assess the long-term stability of the plumes, to calibrate risk models, to aid in establishing remedial priority based on actual risk.

Further study of the impacts of the spill of uranium at BX-102 is necessary to address the risks posed to the environment by this event. Modeling (DOE 2003b) conducted for the representative waste sites in the study area (216-B-38 Trench, 216-B-7A&B Cribs, and the 216-B-46 Crib) show no uranium above the MCL will enter the groundwater for more than 100 years, and the Field Investigation Report for the WMA B-BX-BY (Knepp 2002) indicates it will take 1,000 years. However, there is a uranium plume in groundwater that was reported in 1998 (PNNL 1999) in close proximity to tank BX-102. On the basis of existing borehole control, the vadose zone near tank BX-102 should be mapped in detail. All apparent low permeability layers should be mapped, and isopach maps of contamination (^{238}U, ^{60}Co, ^{125}Sb, and ^{137}Cs) between these layers should be constructed. Groundwater well 299-E33-44 should be logged with the SGLS to delineate the northern extent of the uranium vadose zone plume. Although the perched water zone may be absent, this borehole is key to understanding the contamination profile because of its proximity to the BY Tank Farm and its location midway between boreholes 299-E33-41 and -13, which in addition to 299-E33-44, both exhibit uranium contamination in the groundwater. Historic logging information should be used to track the migration of the uranium vadose zone plume. Annual RAS monitoring of groundwater wells 299-E33-18, 299-E33-41, and 299-E33-44 should be instituted. PNNL's groundwater group should map the temporal changes in groundwater plumes in the area. These results can then be input into models that can be calibrated with actual field results and supported by laboratory studies of soil samples acquired at borehole 299-E33-45. The BX-102 tank leak offers a unique opportunity to calibrate a risk model with actual field results, which will enhance the credibility of the current risk models.

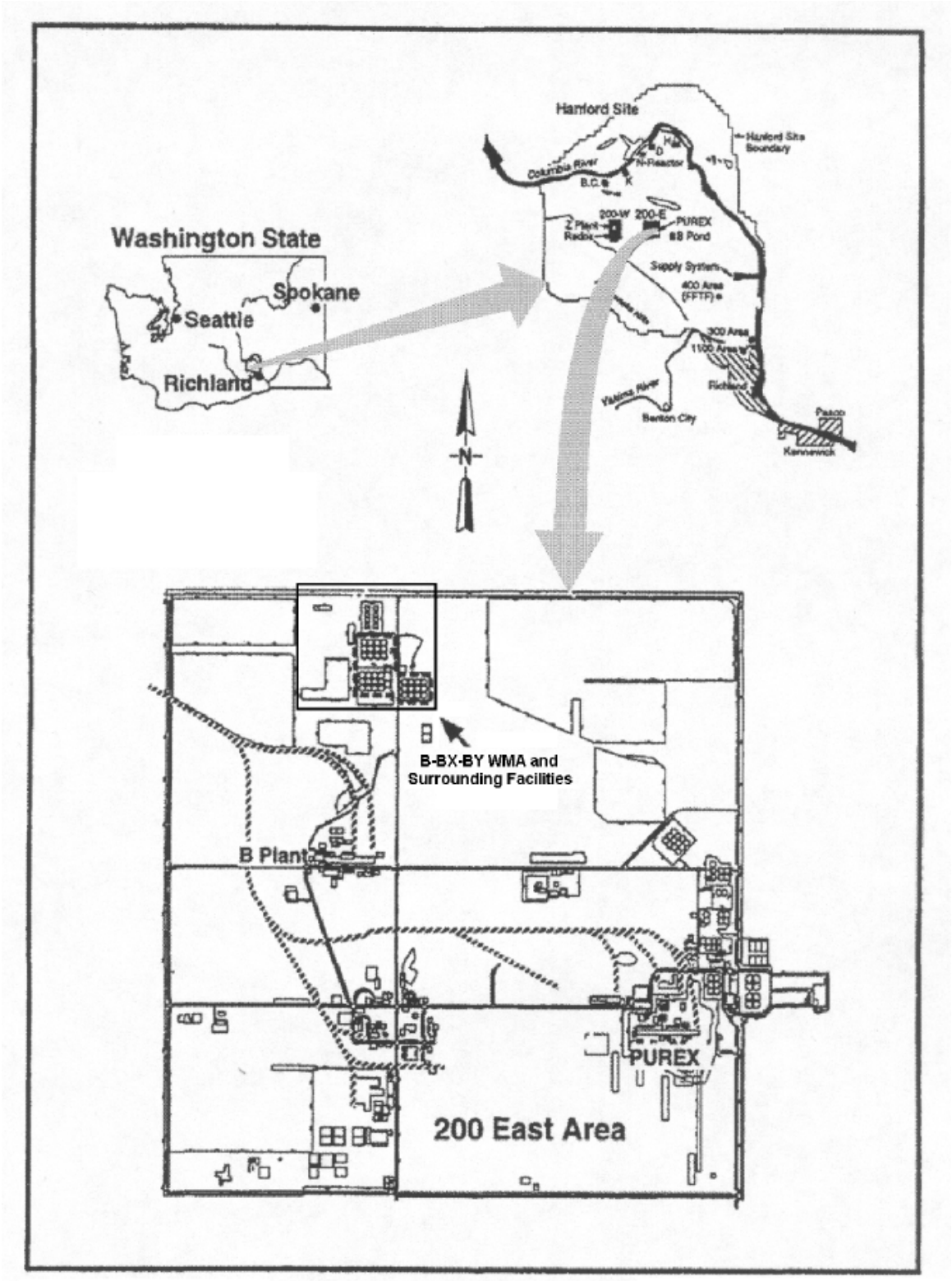
The results of the SGLS logging for both Hanford Tank 200 Areas Baseline Characterization Project and the Hanford Tank Farms Baseline Characterization Project are needed to better comprehend the cumulative impacts to the vadose zone and groundwater near the tank farm waste management areas. Prior to the completion of Tank Farm Field Investigation Reports (e.g., T-TX-TY), all of the boreholes in the surrounding waste sites should be logged with the SGLS. This logging and subsequent evaluation will prevent the reporting of conflicting results from the Tank Farm Field Investigations and the Remedial Investigations of the nearby waste sites such as occurred at the B-BX-BY WMA.

^{99}Tc is a major groundwater contaminant, mobile vadose zone contaminant, and a key contaminant of concern in the B-BX-BY WMA. Evaluation of logging in the area indicates two areas related to the BY Tank Farm where future subsurface investigation efforts should be conducted. Existing boreholes do not define the relationships between waste from the BY Tank Farm and the BY Cribs. The Hanford Soil Inventory Model (Simpson et al. 2001) does not contain estimates of losses to the vadose zone in the BY Tank Farm. The B-BX-BY WMA Field Investigation Report (Knepp 2002) did not evaluate the BY Tank Farm. Soil sample data from boreholes near the BY Tank Farm and BY Cribs should be evaluated to determine relationships between ^{99}Tc and ^{60}Co. These radionuclides are both detected in the vadose zone and within groundwater in the BY Crib area. ^{99}Tc and ^{60}Co appear to have followed similar pathways, and mapping of ^{60}Co using geophysical logging could delineate areas where ^{99}Tc may exist in the vadose zone. A deep borehole northeast of tank BY-107 is needed to determine the source of the deep ^{60}Co and ^{137}Cs in borehole 299-E33-9 and the extent of the ^{99}Tc contamination from tank BY-107. A deep borehole is needed northeast of tank BY-103 to determine the source of the deep ^{60}Co contamination in boreholes 299-E33-9 and -13 and the extent of the ^{99}Tc contamination from tank BY-103. These data are necessary for the eventual closure of the BY Tank Farm.

It is recommended that the Hanford Soil Inventory Model (Simpson et al. 2001) be updated. Leak volume estimates are not available for 10 single-shell tanks (Table 3-2) that are listed as known or assumed leakers in Hanlon (2003). Release estimates are not available for the 216-B-50 and -57 Cribs. SGLS logging indicates that the majority of the uranium contamination in the vadose zone is associated with the 1951 spill at tank BX-102. The current estimates of uranium releases at the 216-B-37 Trench, BY Cribs, 216-B-8 Crib and Tile Field, and 216-B-7A&B Cribs are too high. SGLS logging indicates that the majority of the ^{60}Co contamination in the vadose zone is associated with the BY Cribs. The current estimate of ^{60}Co releases at the B Tank Farm is too high, and the estimates for the BY Cribs are too low. Uranium and ^{60}Co release estimates should be changed to more accurately reflect the results of the SGLS logging. This update is needed to enhance the validity and credibility of the future risk assessments and the SAC.

Figures

The following section presents the figures cited in this report in the order in which they were presented.



Modified from Narbutovskih (2000)

Figure 1. Location Map of the Hanford Site and 200 East Area

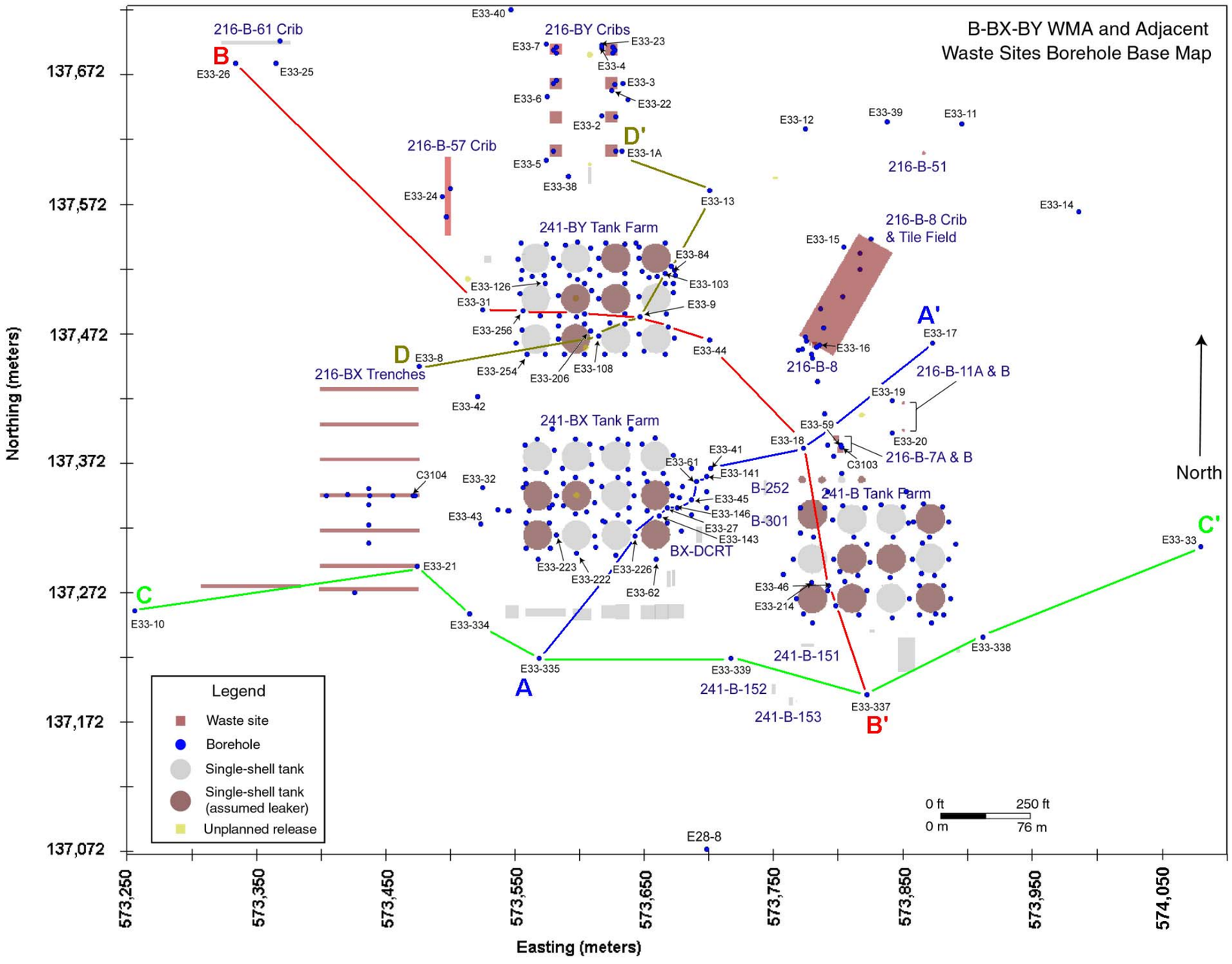
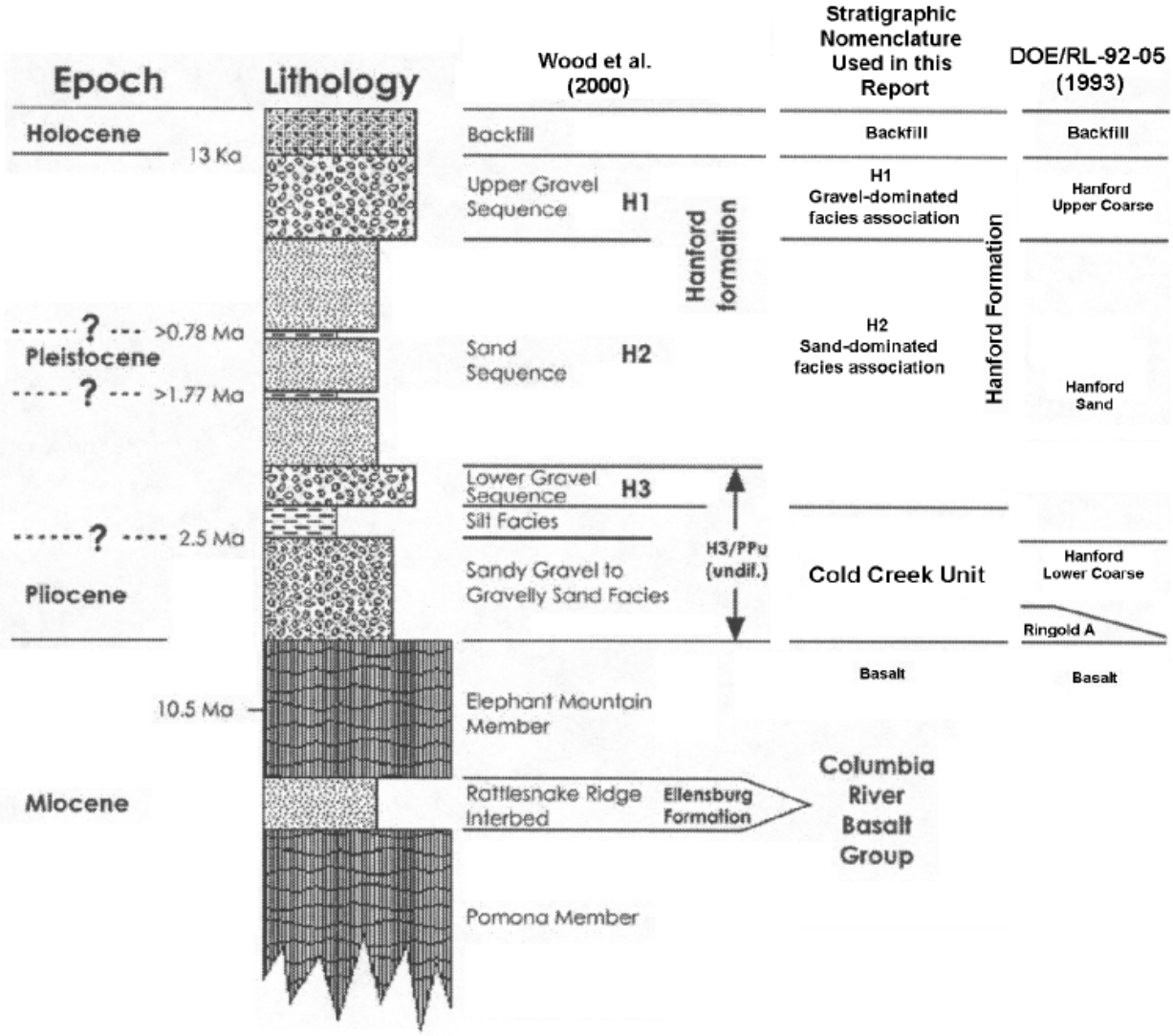
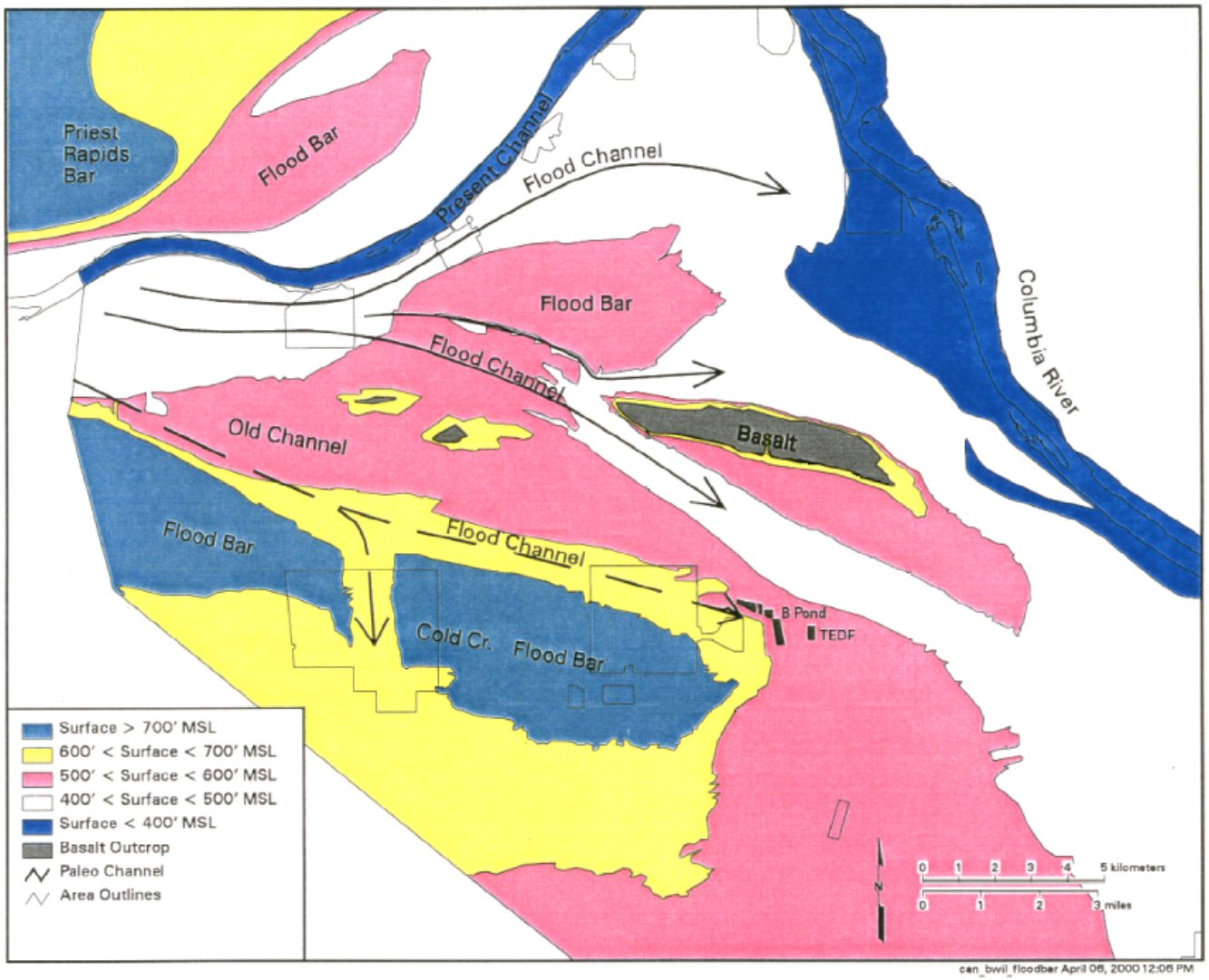


Figure 2. Map of the B-BX-BY Waste Management Area and Adjacent Waste Sites, Boreholes, and Cross Sections



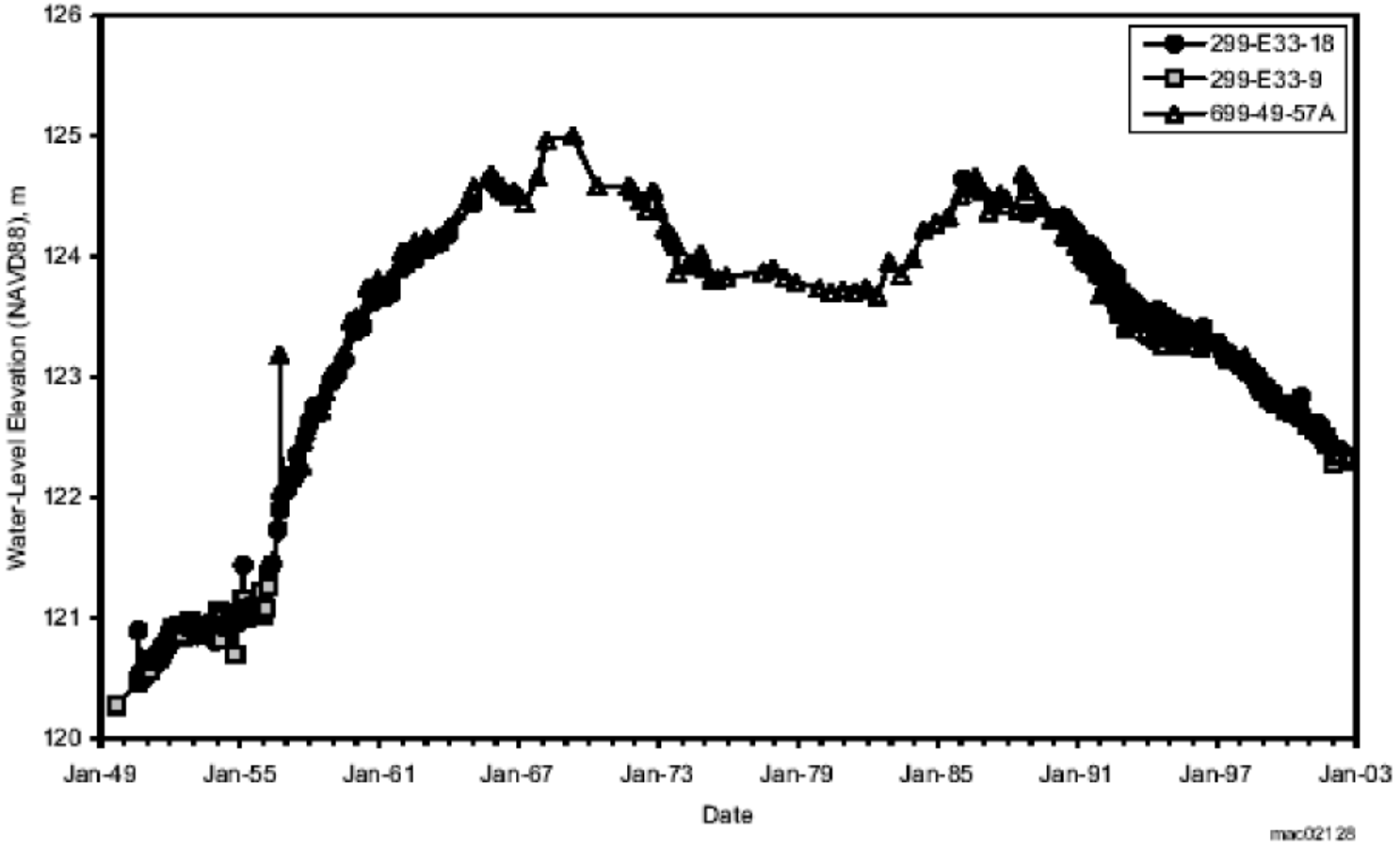
Modified from Wood et al. (2000a)

Figure 3. General Stratigraphy of the B-BX-BY Waste Management Area



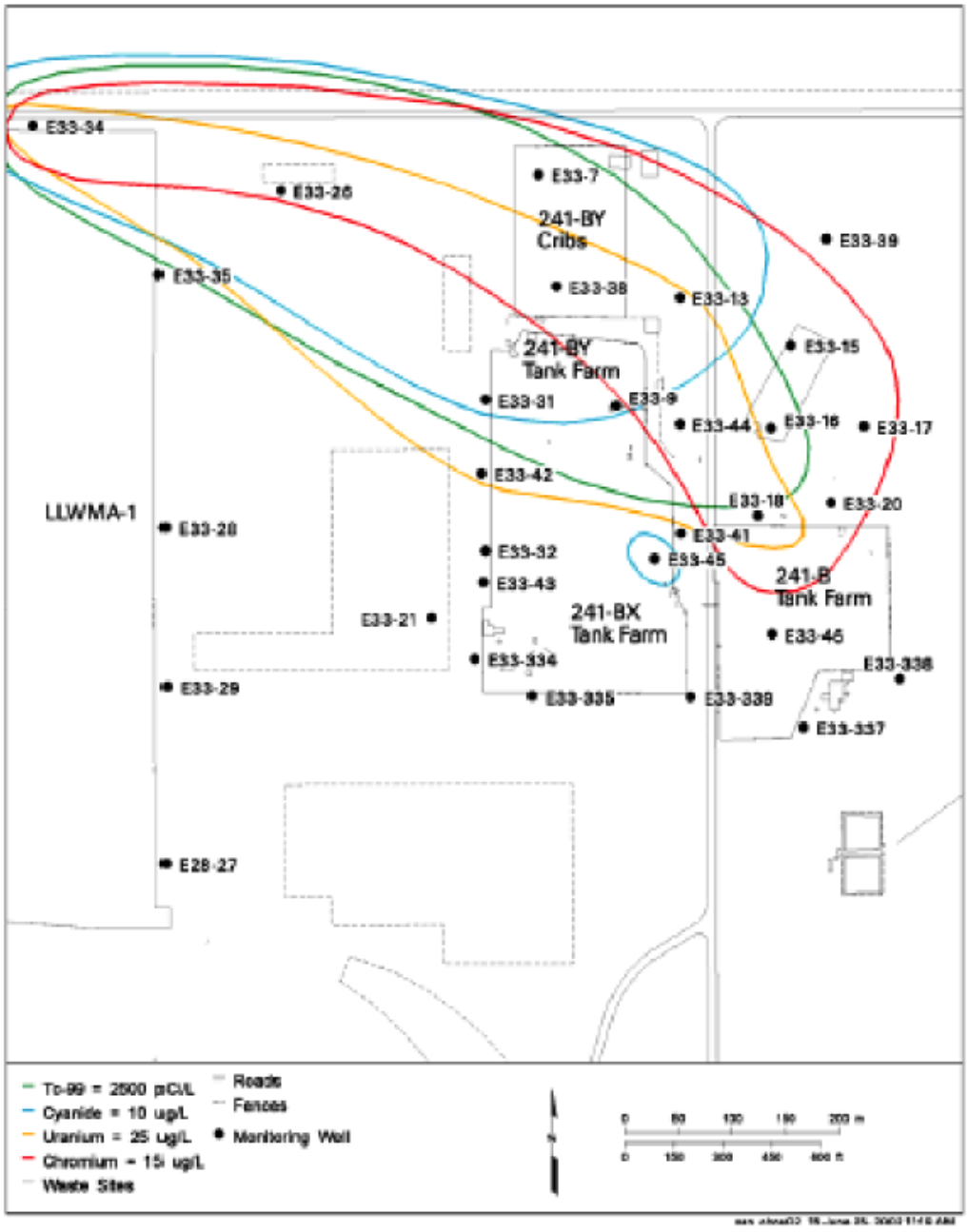
From Williams et al. (2000)

Figure 4. Topographic Illustration of Pleistocene Flood-Channels and the Present Day Columbia River Channel Pathways, Hanford Site, Washington



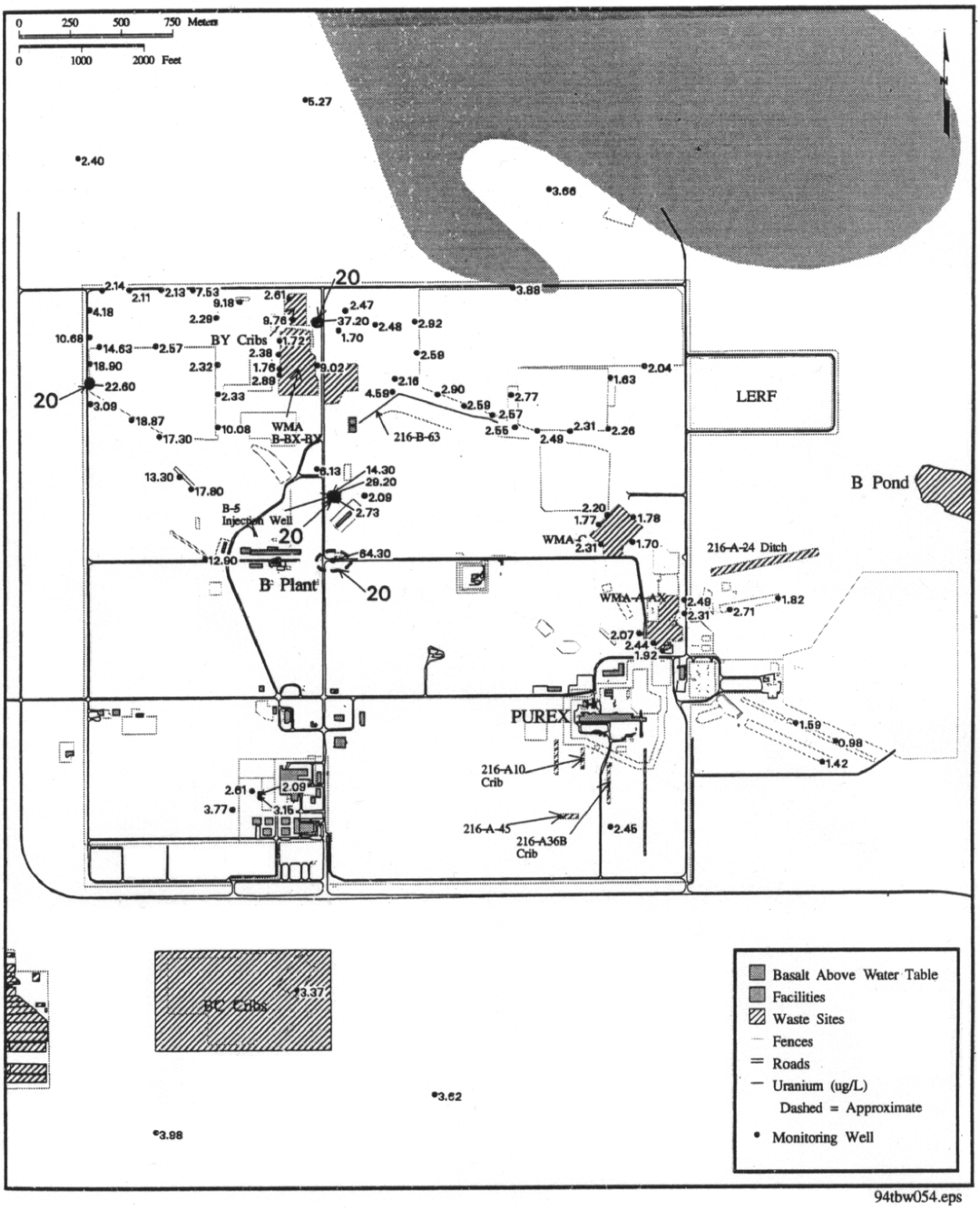
From PNNL (2003)

Figure 5. Groundwater Levels in the Northwest 200 East Area



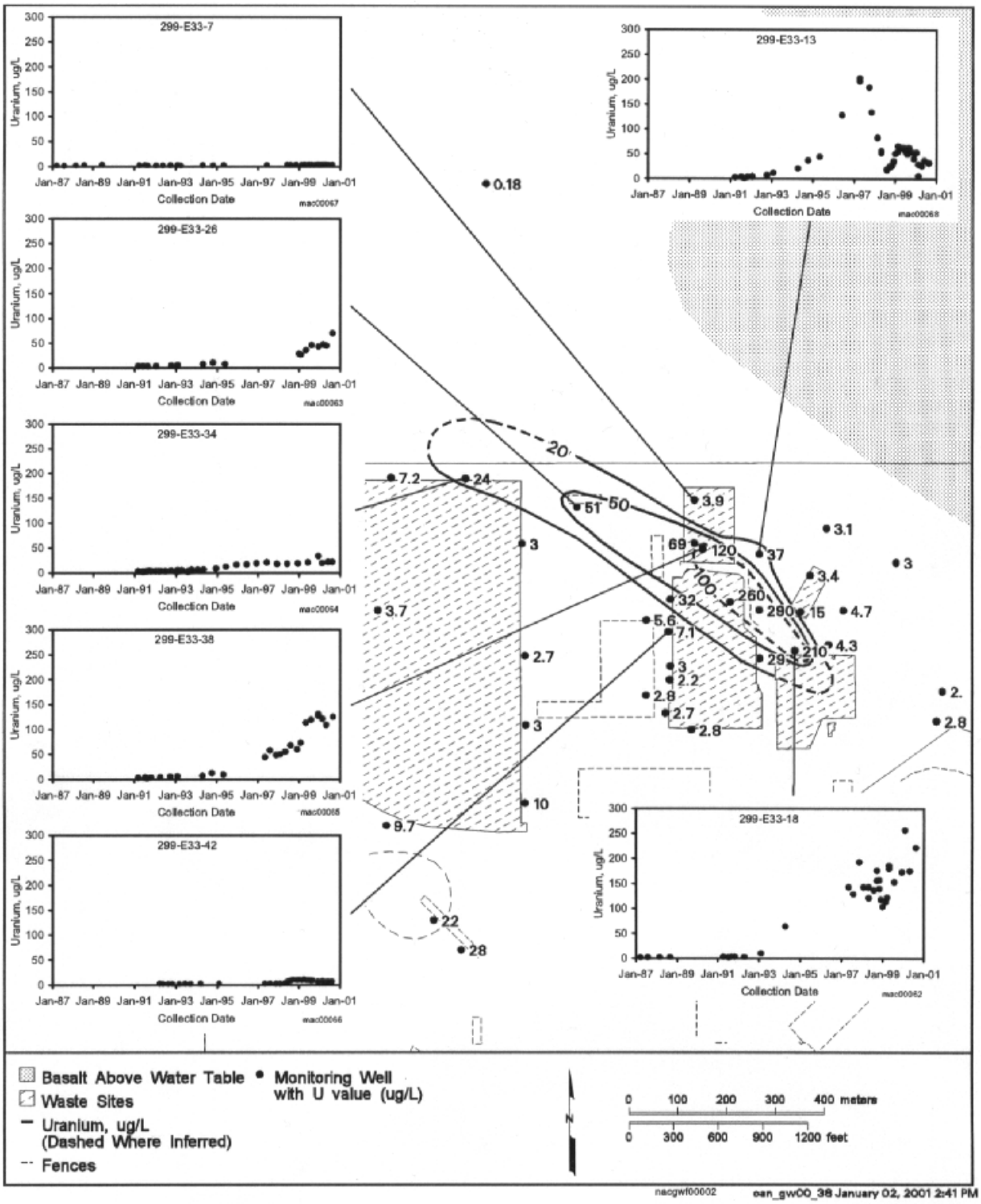
From Knepp (2002)

Figure 6. Outline of Major Groundwater Plumes near the B-BX-BY WMA



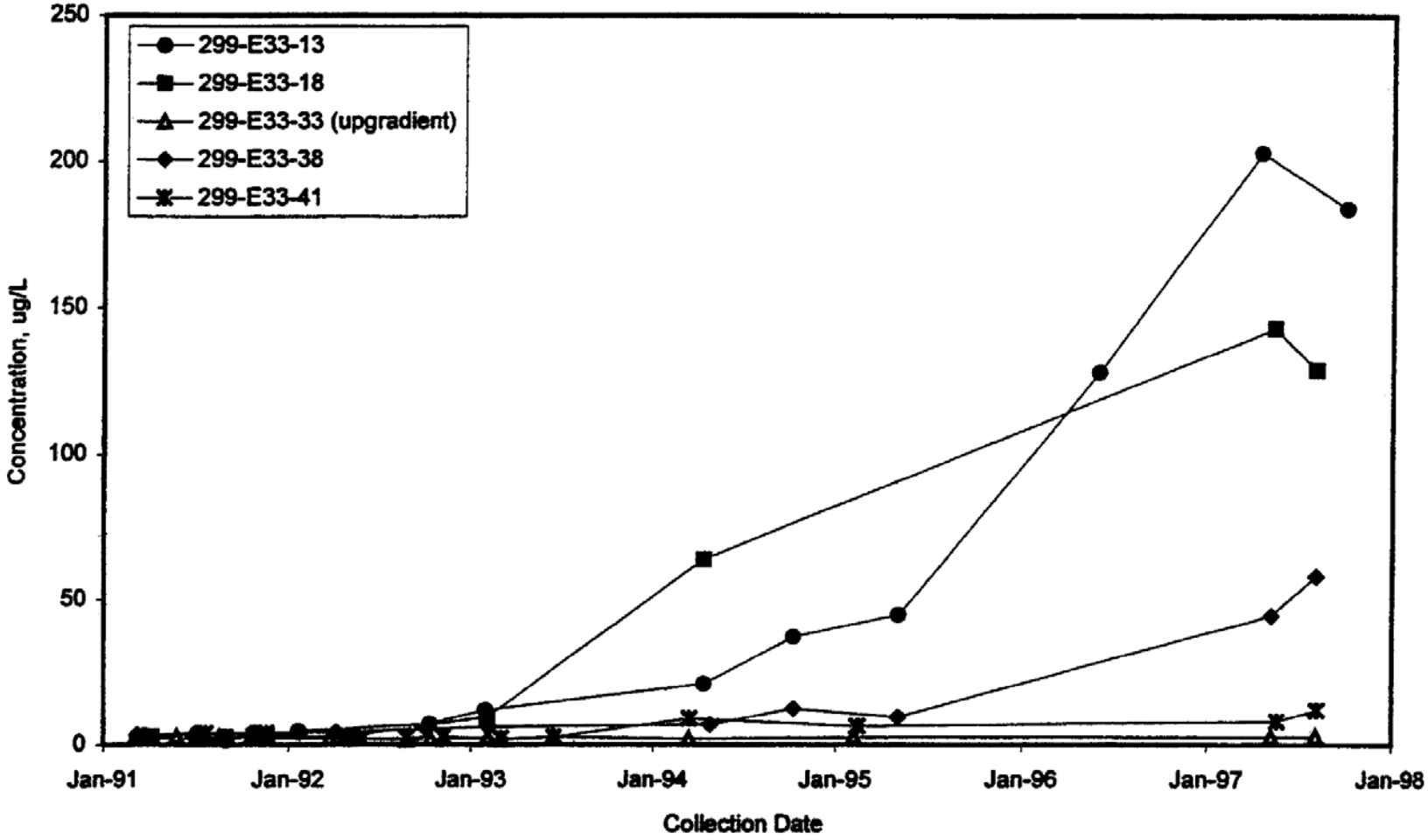
From PNNL (1995)

Figure 7. 1994 Average Uranium Concentrations in Groundwater, 200 East Area



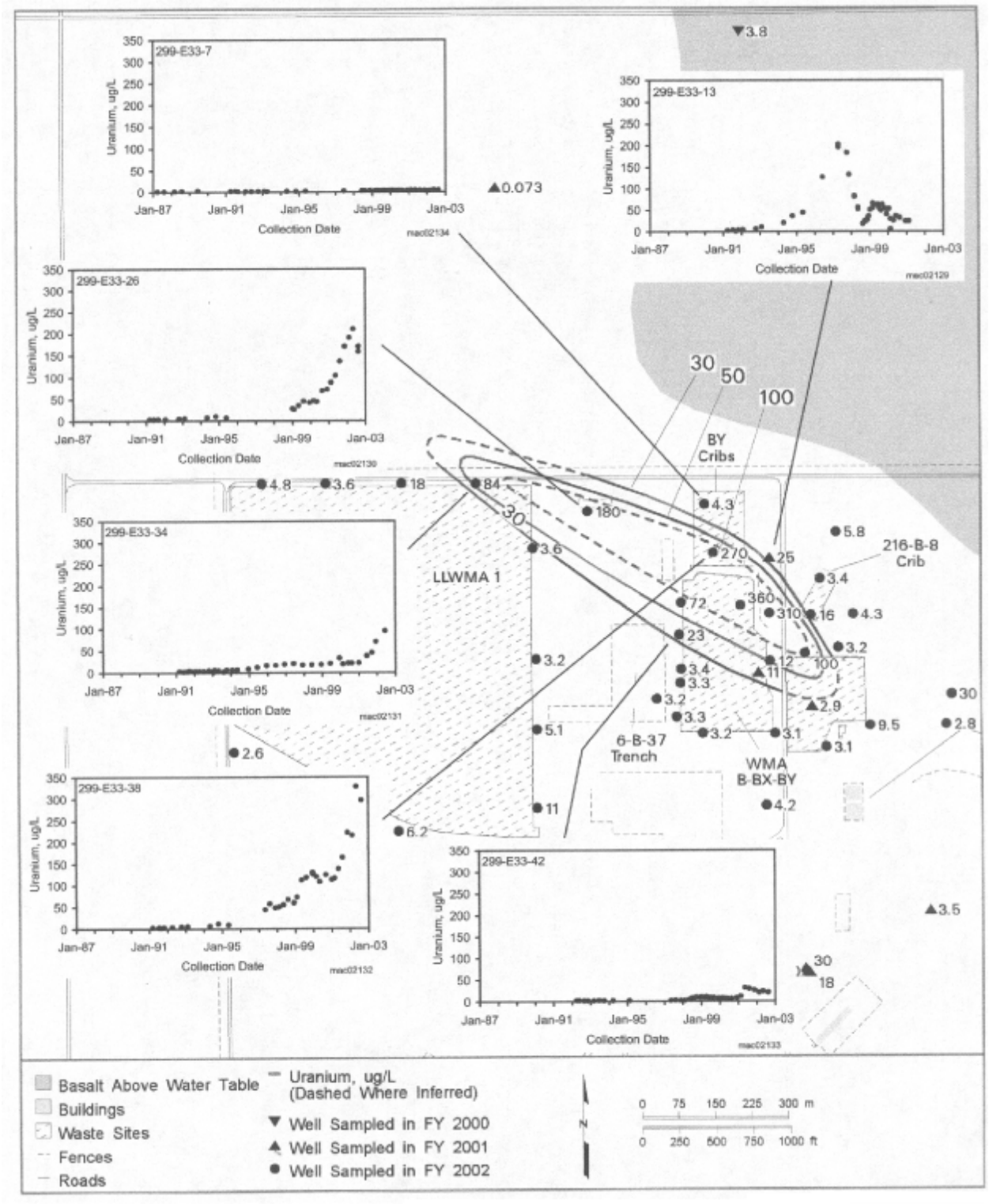
From PNNL (2001)

Figure 8. 2000 Average Uranium Concentrations in Groundwater, B-BX-BY WMA



From PNNL (1998)

Figure 9. Uranium Concentrations in Wells in the Vicinity of the B-BX-BY WMA



From PNNL (2003)

Figure 10. 2002 Average Uranium Concentrations in Groundwater, B-BX-BY WMA

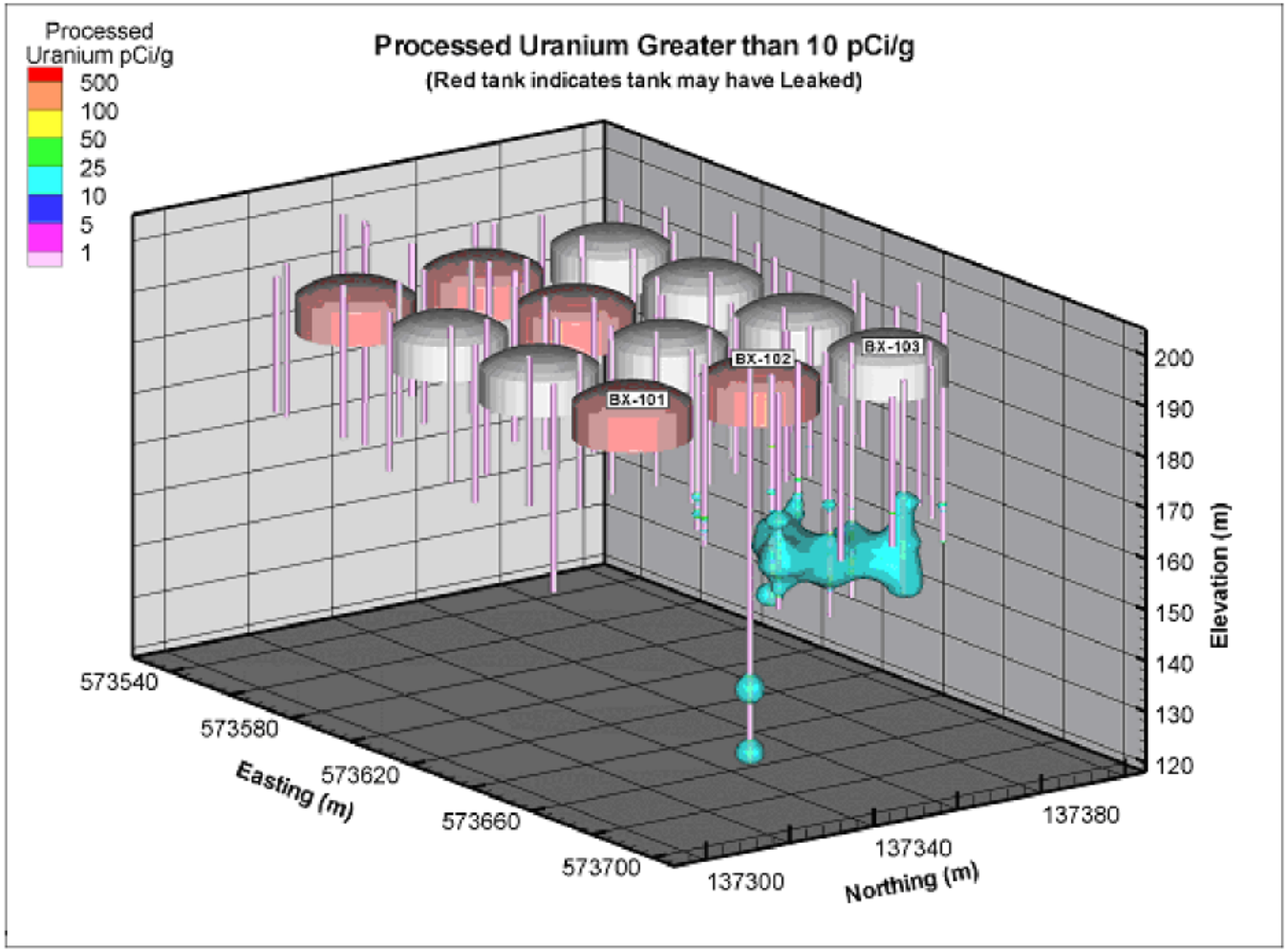
From 9989-NEG-B

Figure 11. 1954 Photograph of a BX Trench, Looking to the West

Figure 12. 1944 Photograph of the B Tank Farm, Looking to the South

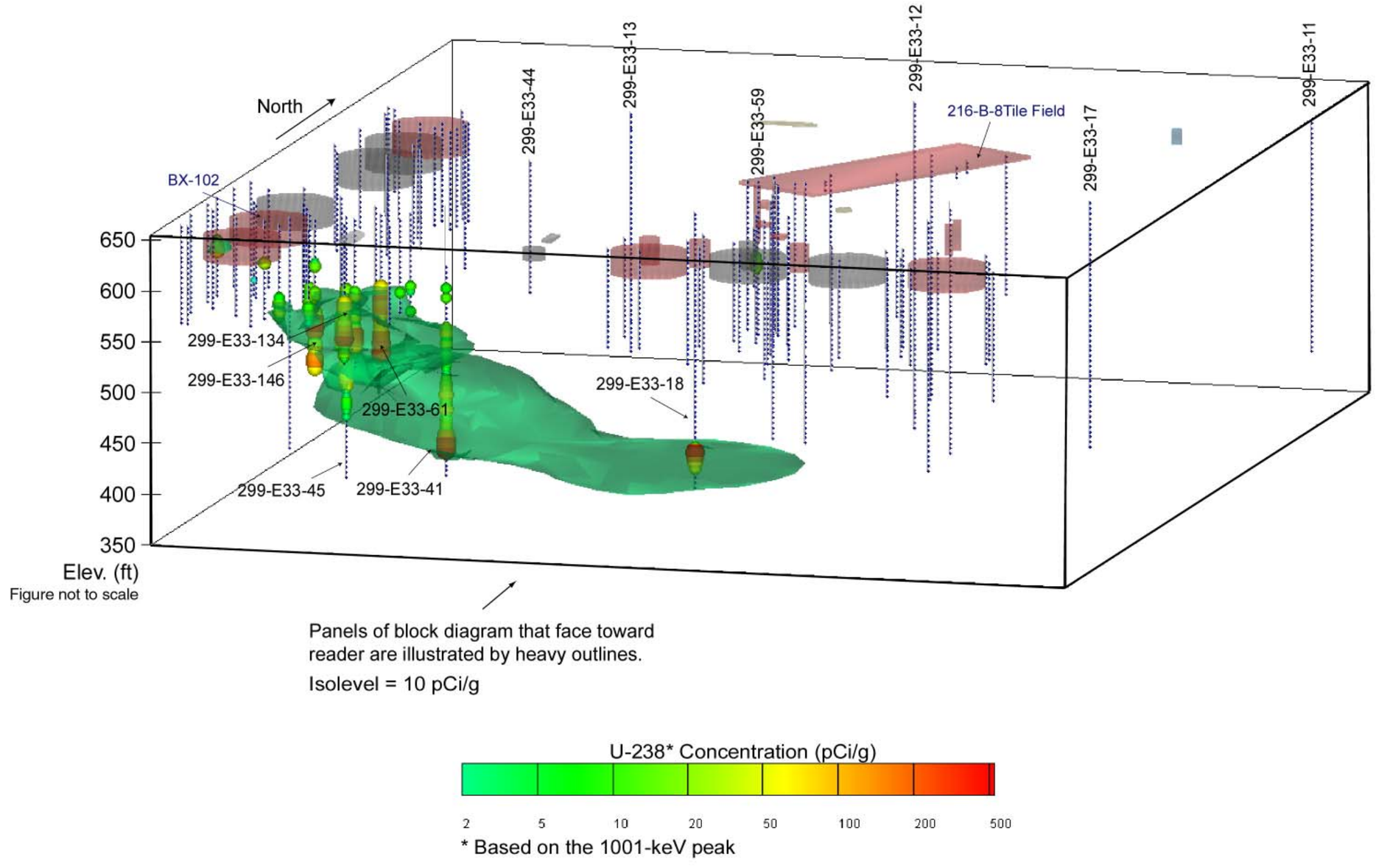
Figure 13. 1947 Photograph of the BX Tank Farm, Looking to the Northeast

Figure 14. 1949 Photograph of the BY Tank Farm, Looking to the Northeast



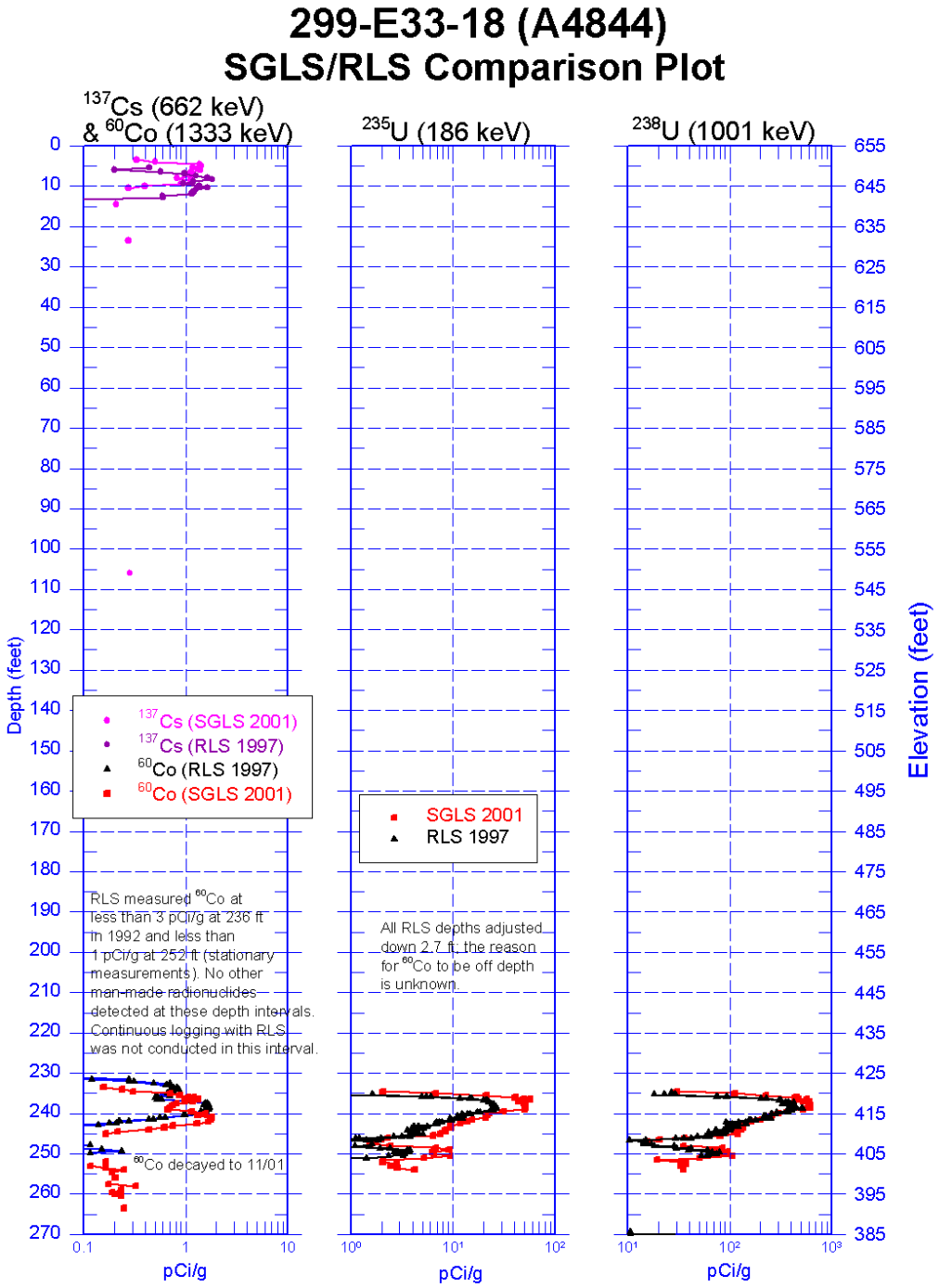
From Knepp (2002)

Figure 15. Projected Three-Dimensional Image of the Soil near Tank BX-102 Contaminated with Processed Uranium Greater than 10 pCi/g



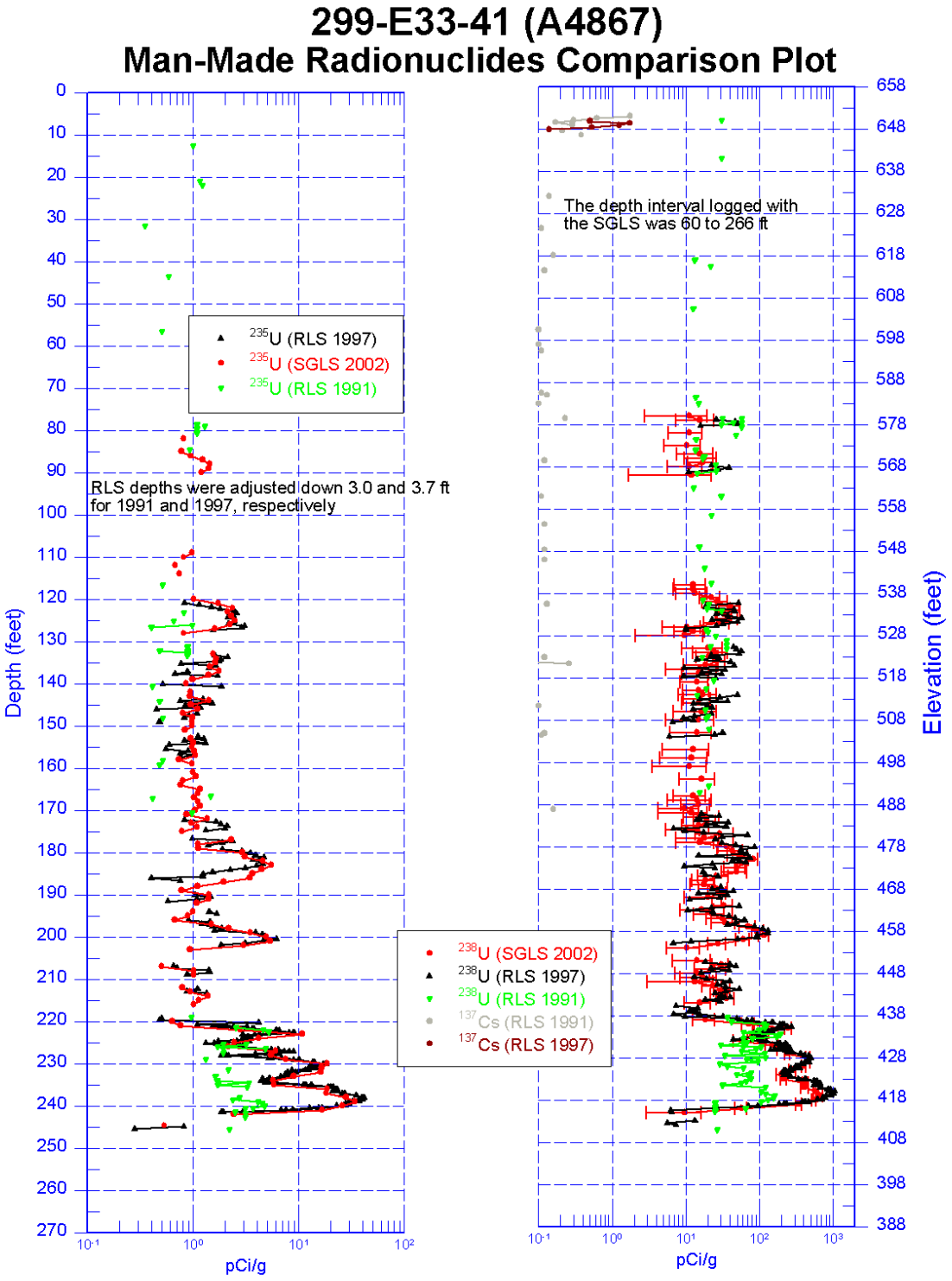
From DOE (2002b)

Figure 16. Visualization of the ^{238}U Area of Contamination Northeast of Tank BX-102



Modified from DOE (2002b)

Figure 17. Borehole 299-E33-18 SGLS/RLS Comparison Plot



Modified from (DOE 2002b)

Figure 18. Borehole 299-E33-41 SGLS/RLS Comparison Plot

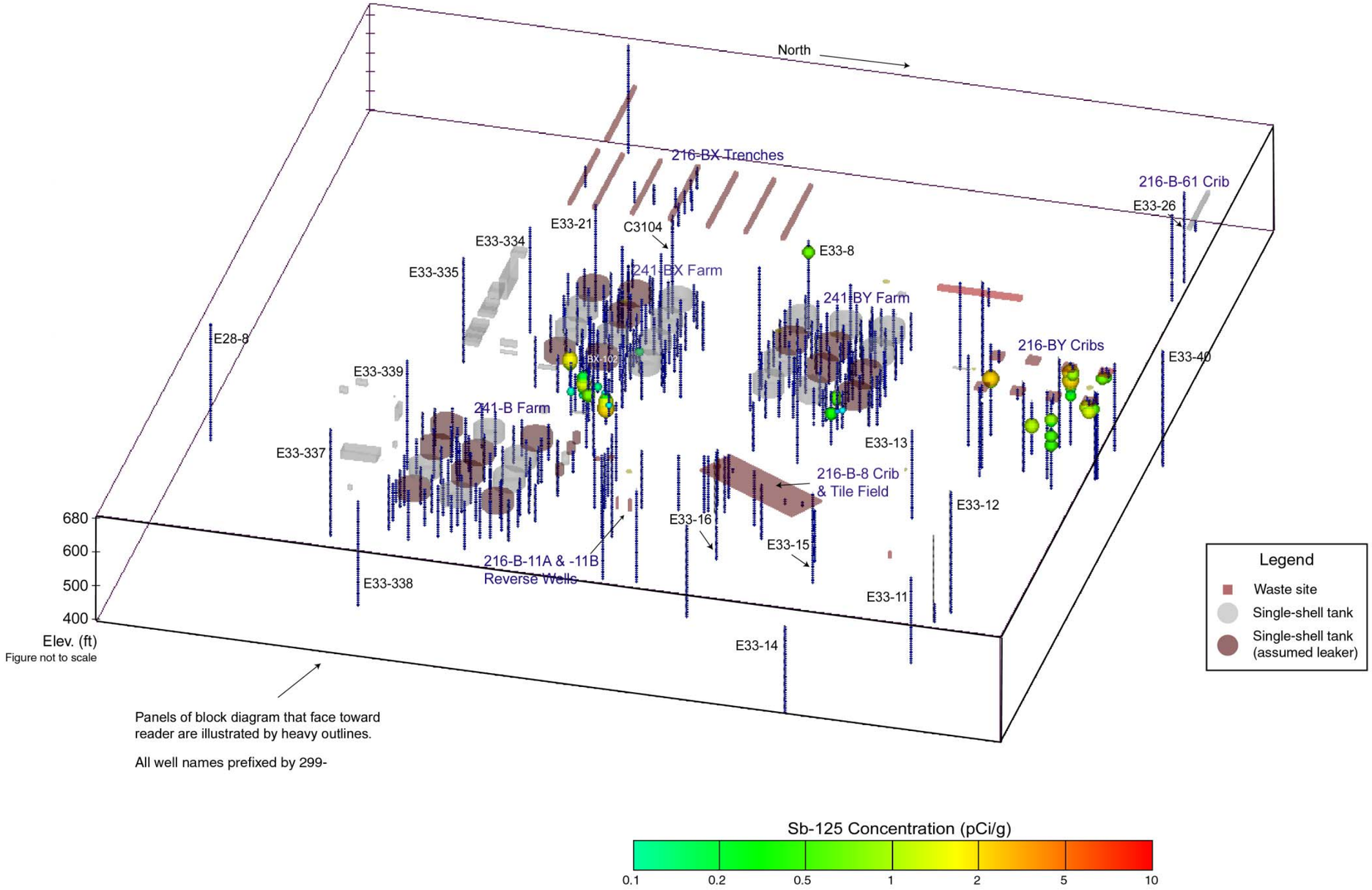


Figure 19. Visualization of the ^{125}Sb Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

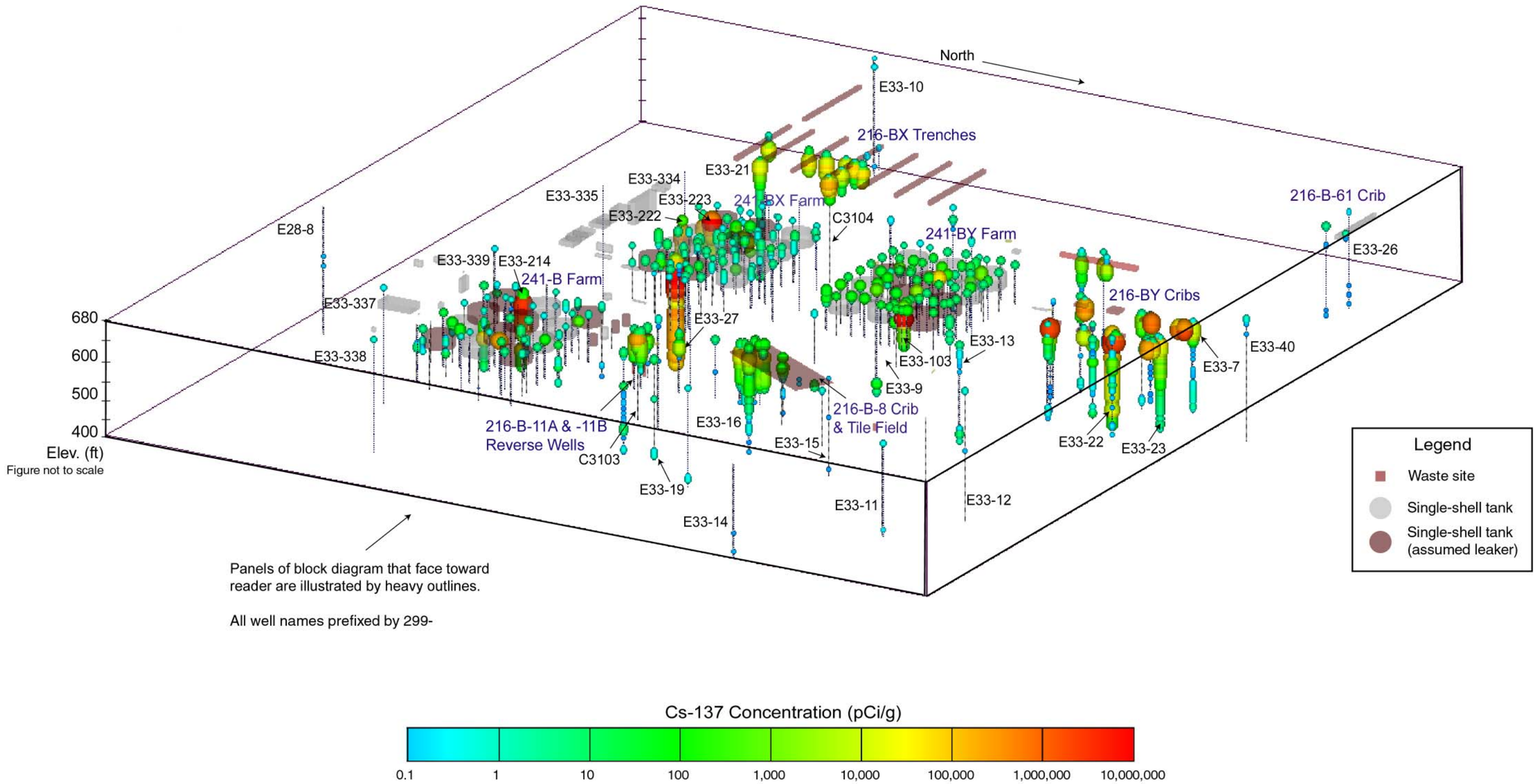


Figure 20. Visualization of the ^{137}Cs Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

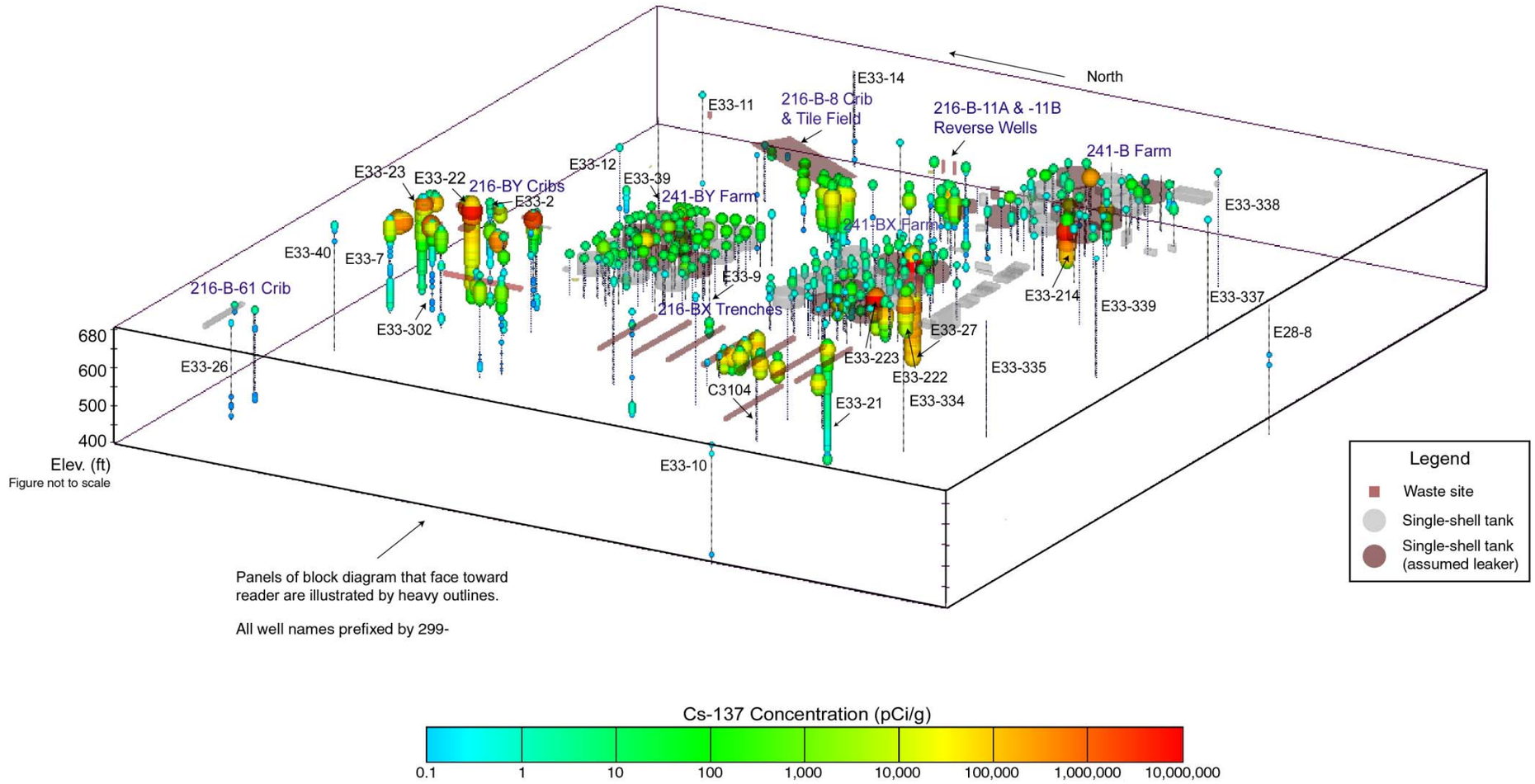


Figure 21. Visualization of the ^{137}Cs Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Southwest

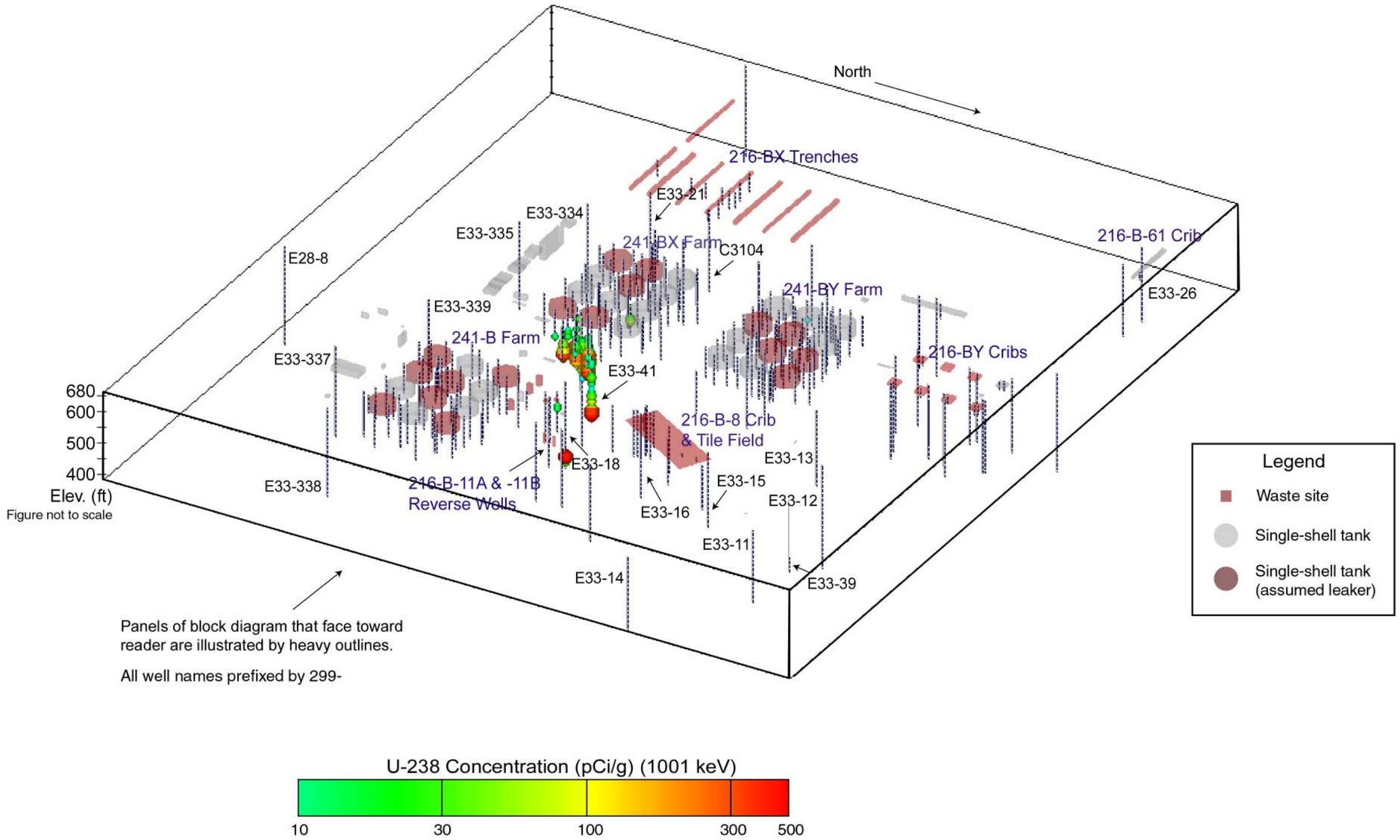


Figure 22. Visualization of the ^{238}U (1001 keV) Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

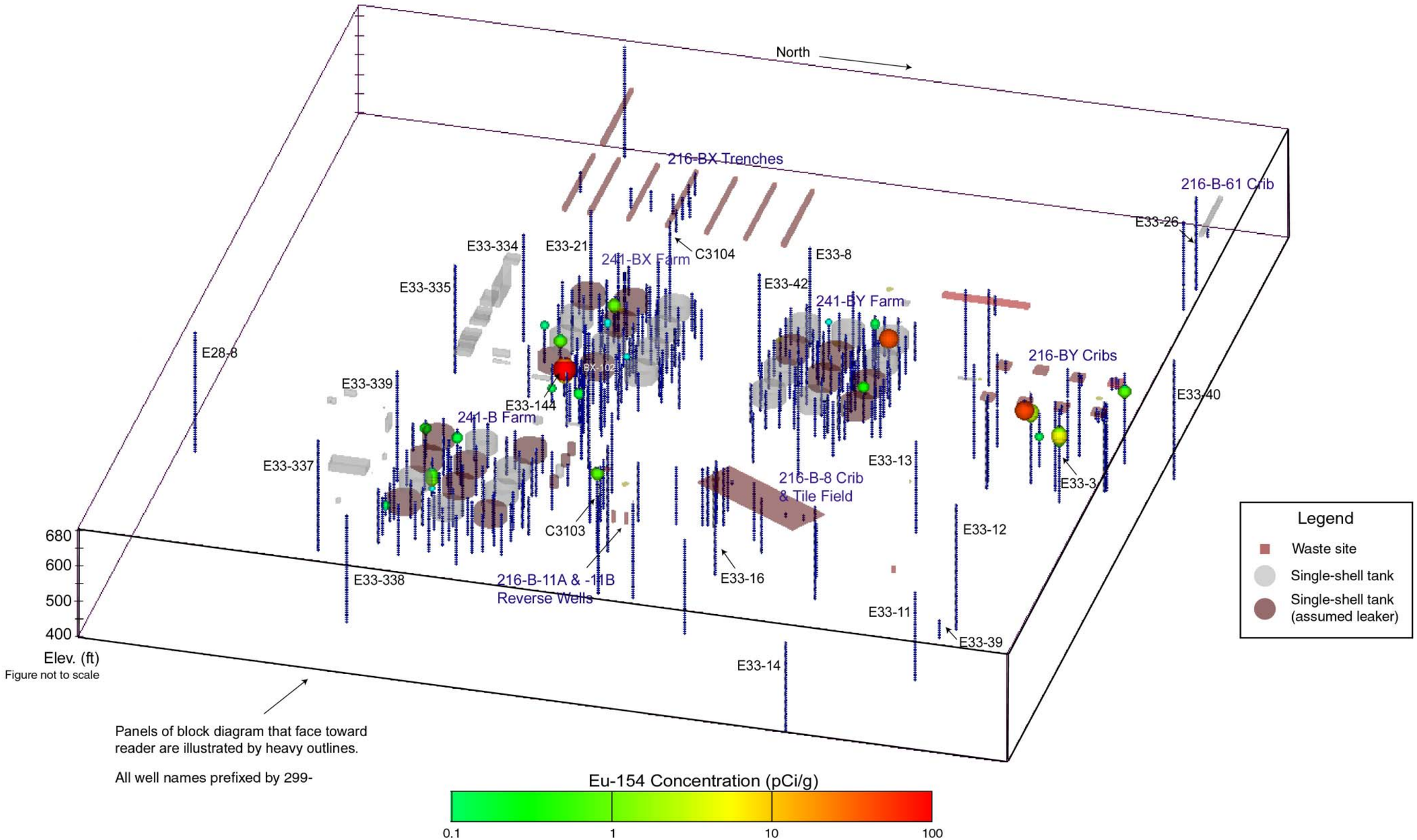


Figure 23. Visualization of the ^{154}Eu Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

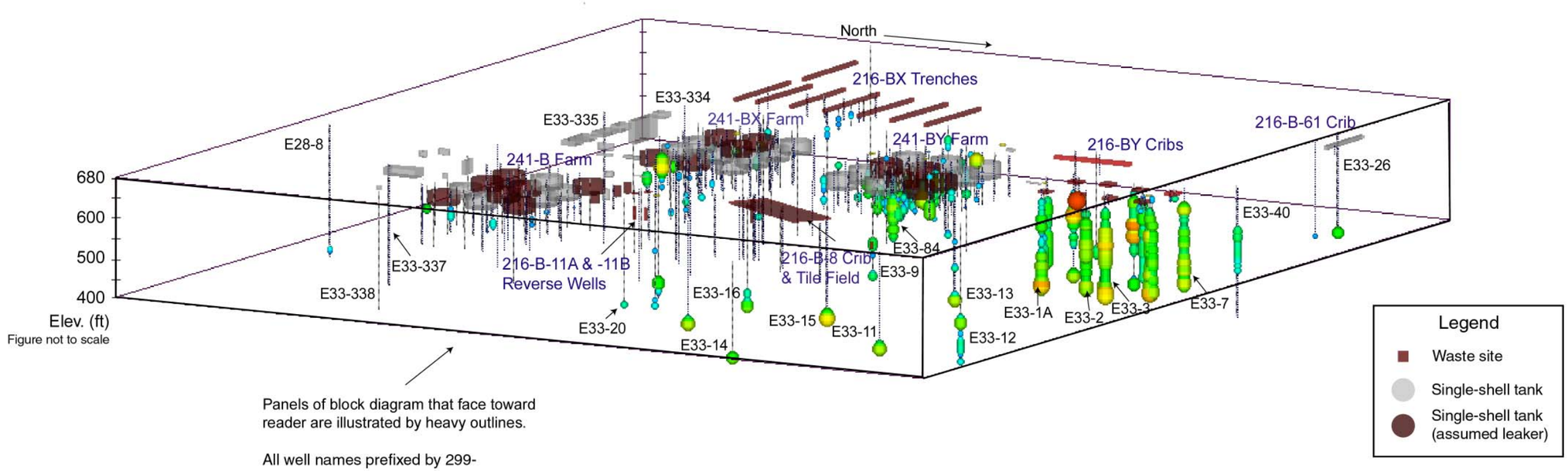


Figure 24. Visualization of the ^{60}Co Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

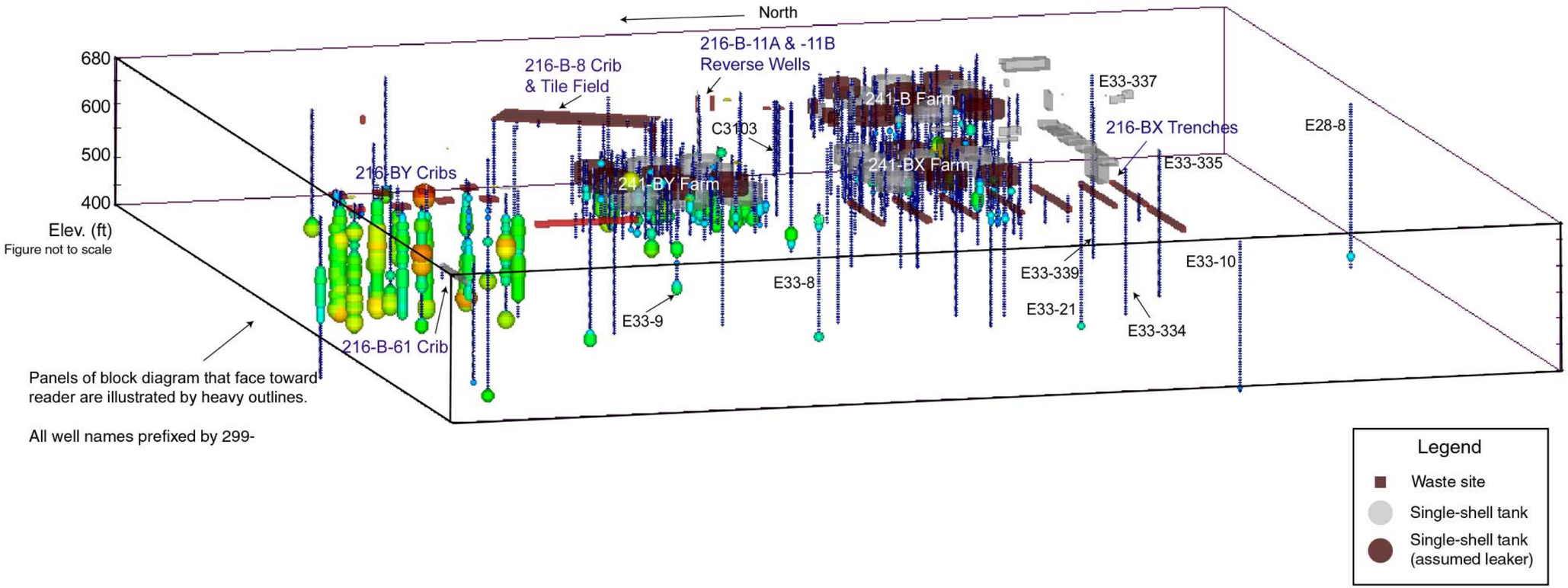


Figure 25. Visualization of the ^{60}Co Data Acquired at the B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northwest

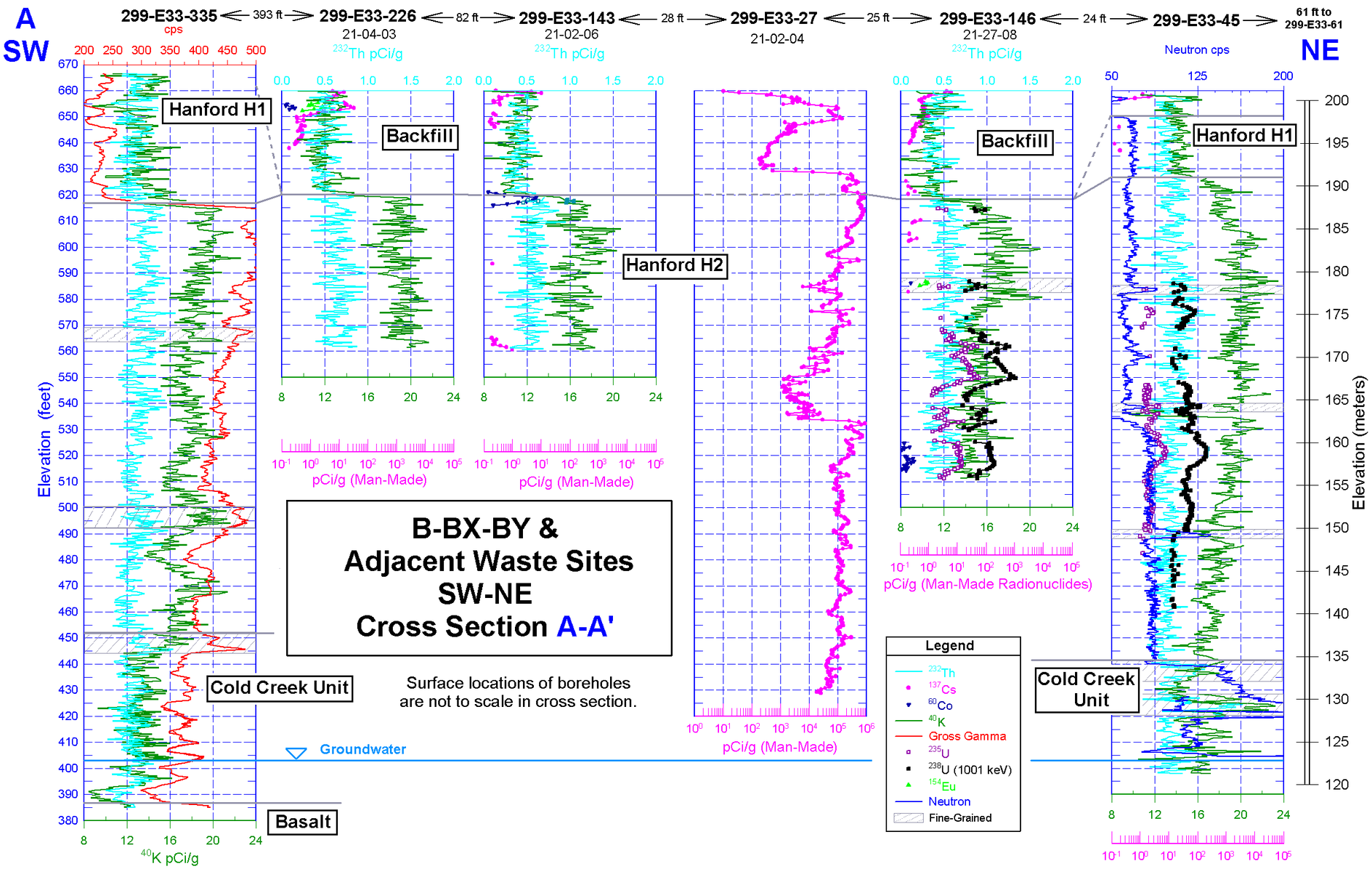


Figure 26a. Southwest-Northeast Cross Section A-A' Showing Contamination and Interpreted Stratigraphy through the BX Tank Farm and 216-B-7A & -7B Cribs and near the 216-B-11A Reverse Well

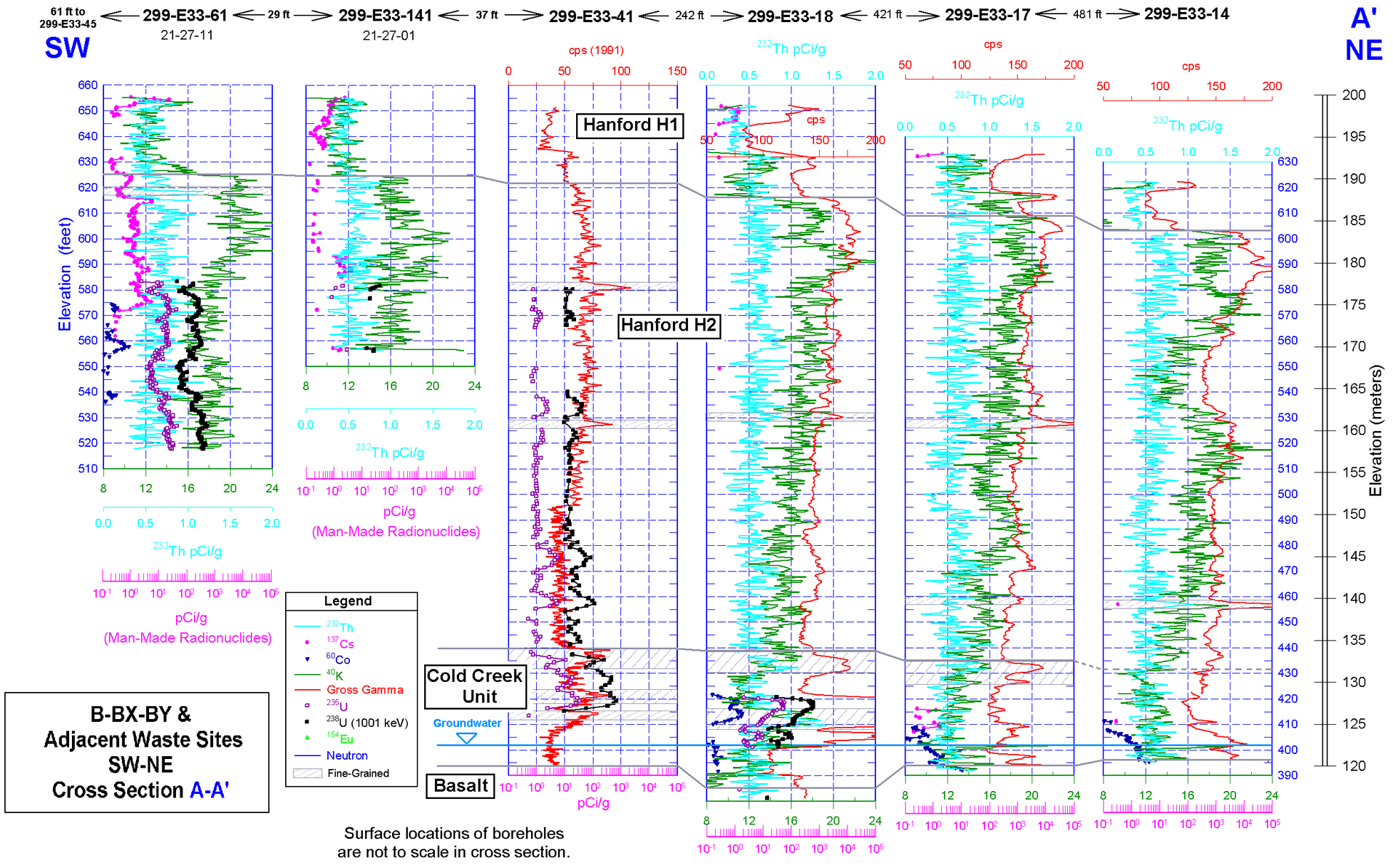


Figure 26b. Southwest-Northeast Cross Section A-A' Showing Contamination and Interpreted Stratigraphy through the BX Tank Farm and 216-B-7A & -7B Cribs and near the 216-B-11A Reverse Well

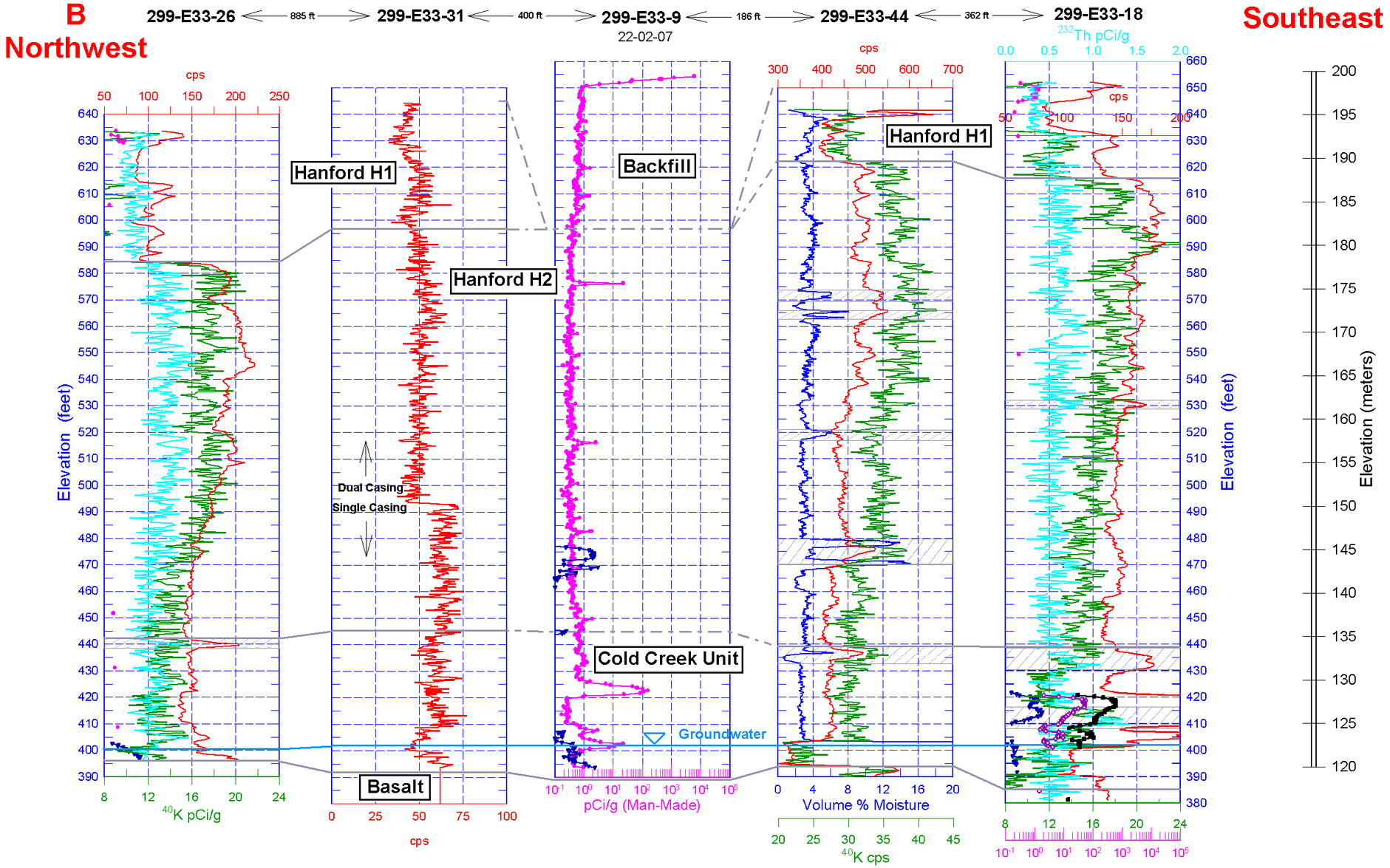


Figure 27a. Northwest-Southeast Cross Section B-B' Showing Contamination and Interpreted Stratigraphy through the B and BY Tank Farms, 216-B-7A & -7B Cribs, and 216-B-61 Crib

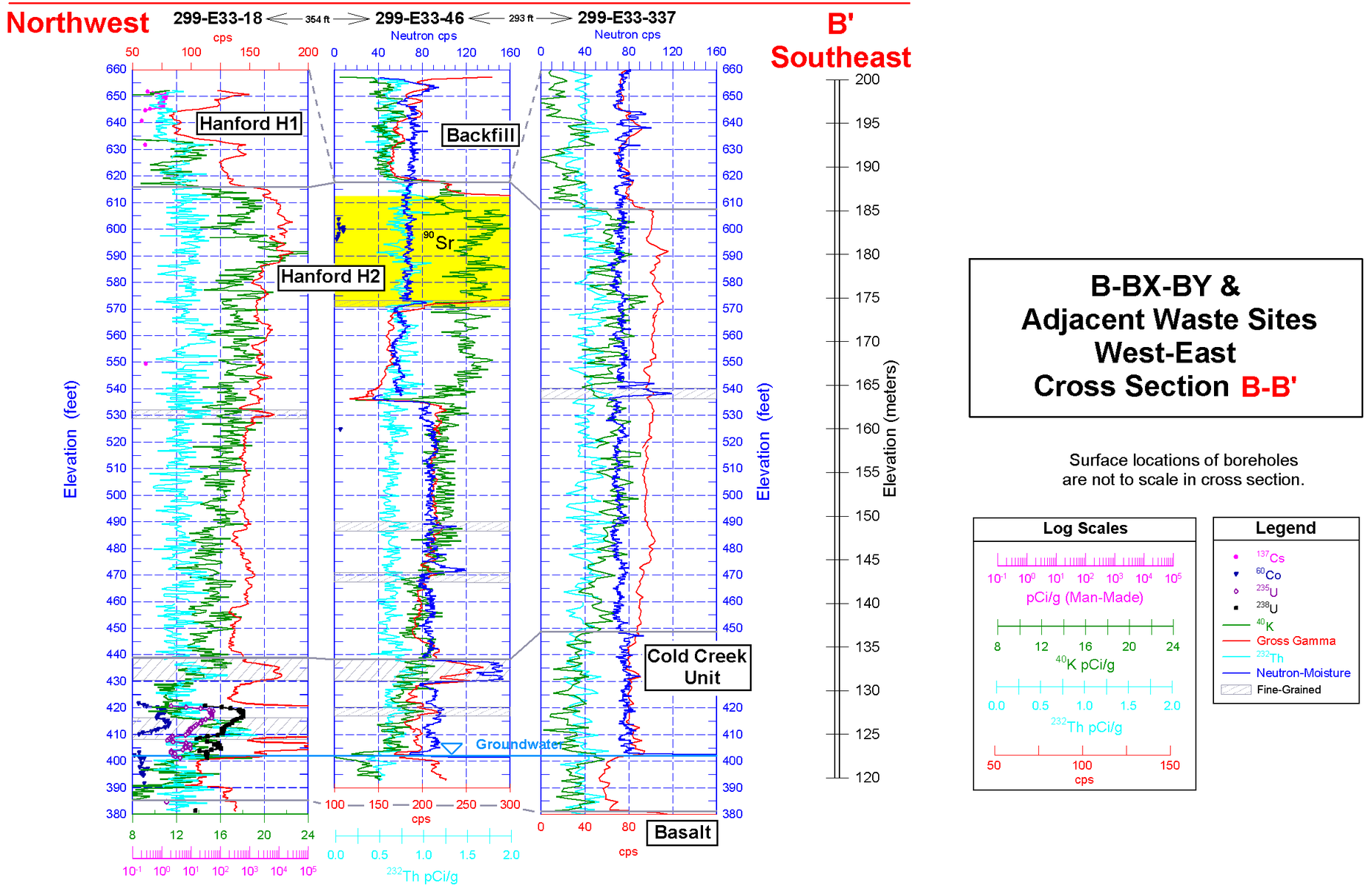


Figure 27b. Northwest-Southeast Cross Section B-B' Showing Contamination and Interpreted Stratigraphy through the B and BY Tank Farms, 216-B-7A & -7B Cribs, and 216-B-61 Crib

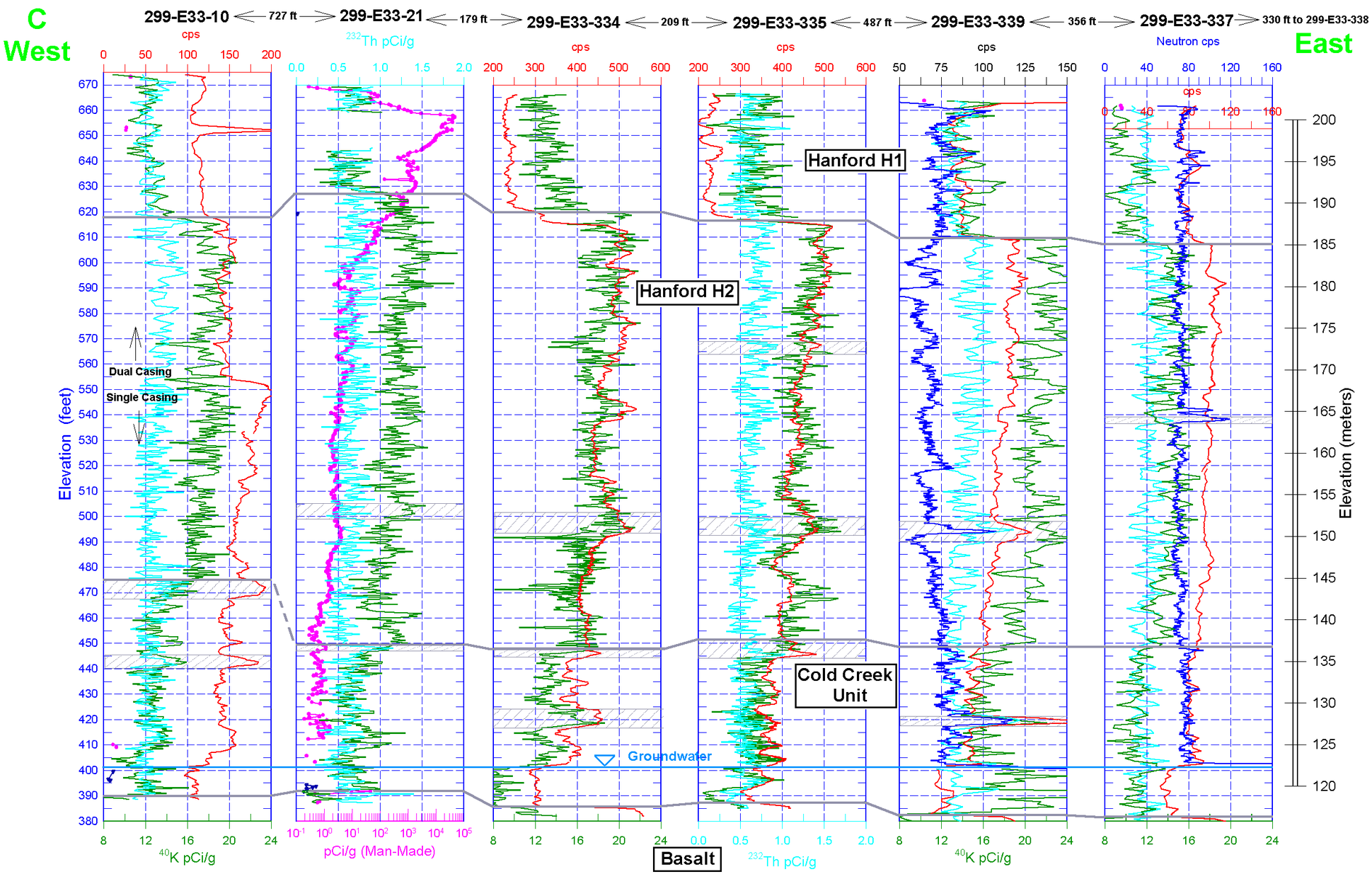
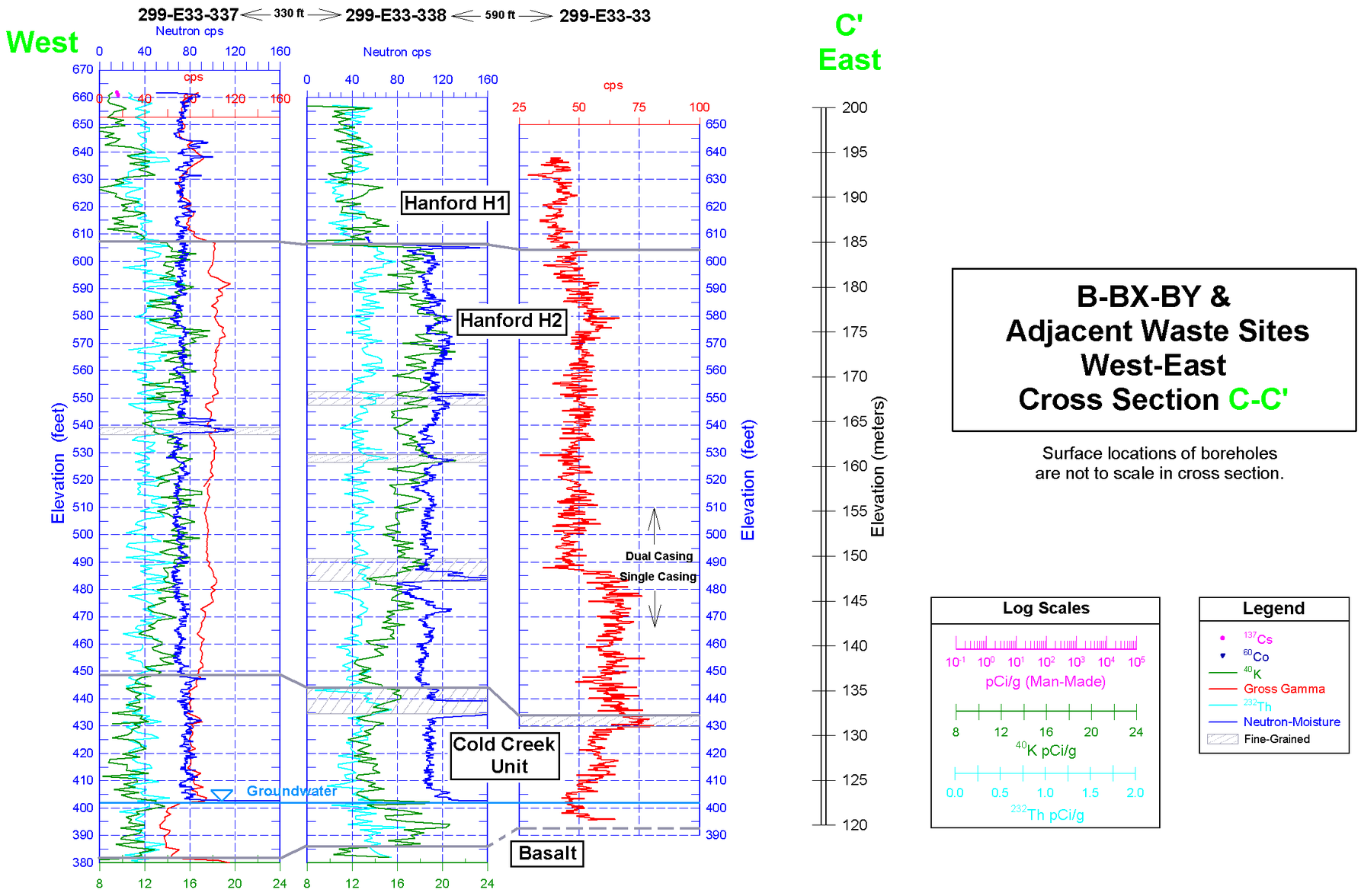


Figure 28a. East-West Cross Section C-C' Showing Contamination and Interpreted Stratigraphy through the 216-B-42, -36, and -35 Trenches and South of the B and BX Tank Farms



B-BX-BY & Adjacent Waste Sites West-East Cross Section C-C'

Surface locations of boreholes are not to scale in cross section.

Figure 28b. East-West Cross Section C-C' Showing Contamination and Interpreted Stratigraphy through the 216-B-42, -36, and -35 Trenches and South of the B and BX Tank Farms

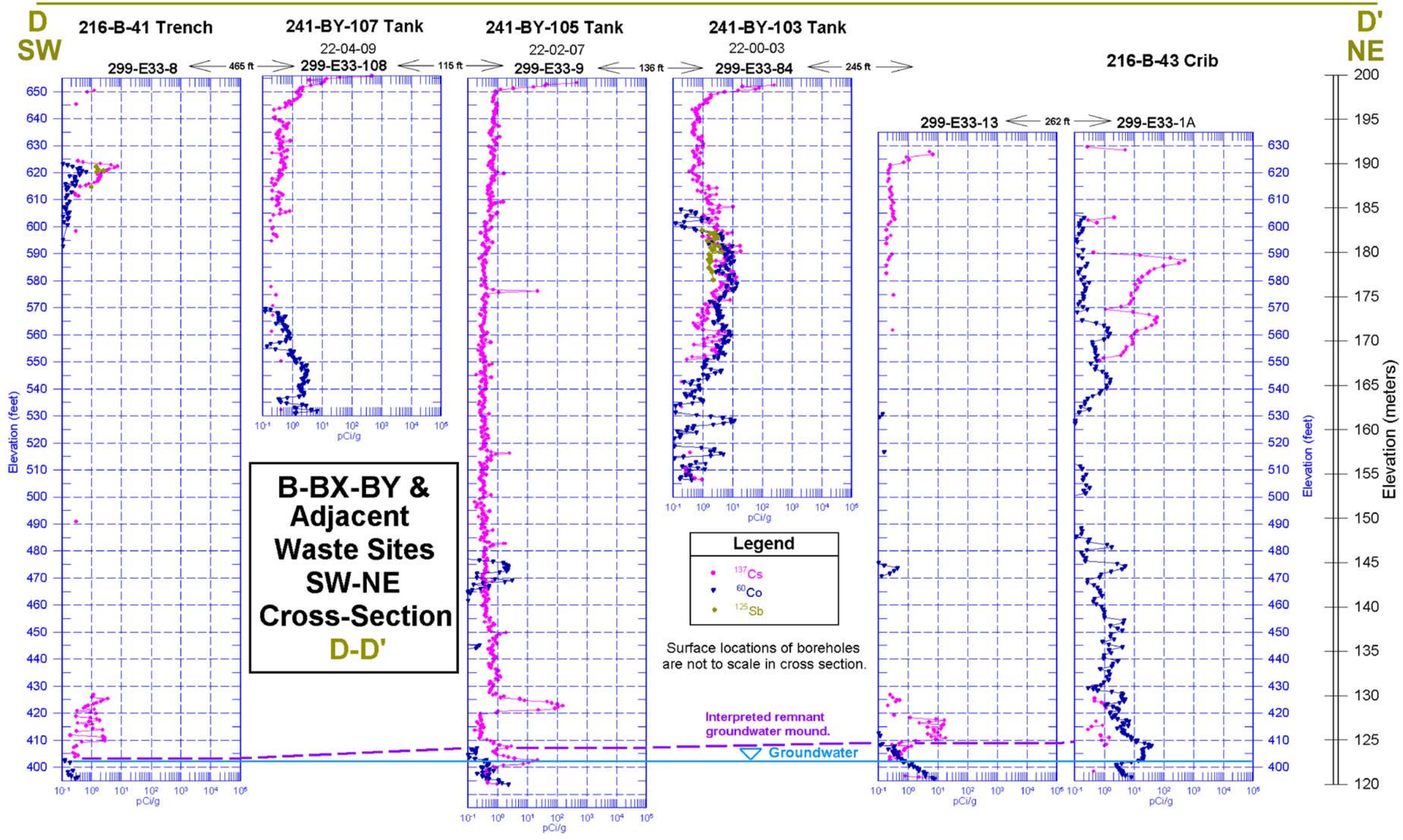


Figure 29. Cross Section D-D' Showing Contamination near the 216-B-41 Trench and in the BY Tank Farm and 216-B-43 Crib

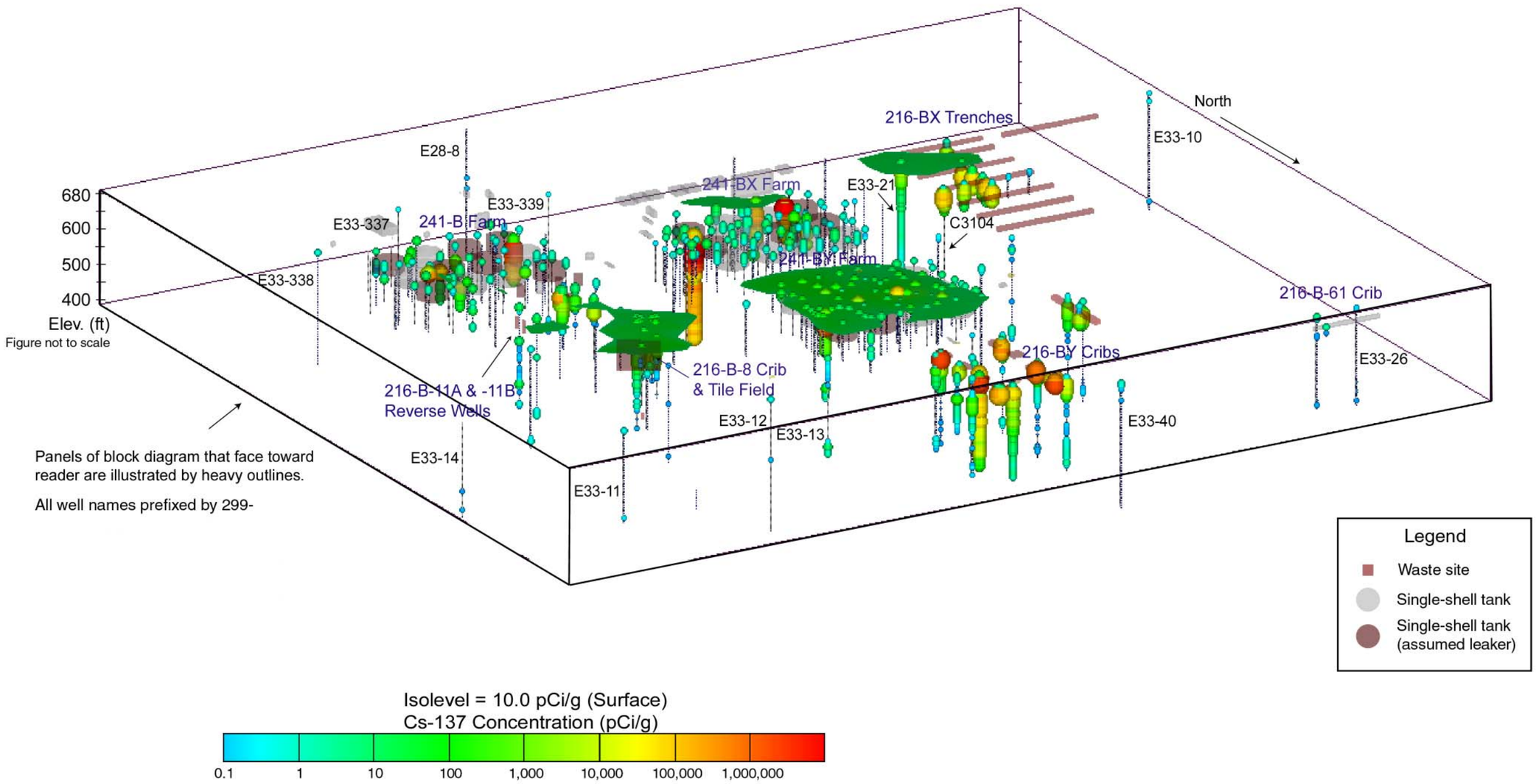


Figure 30. Visualization of ^{137}Cs Surface Areas of Contamination, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

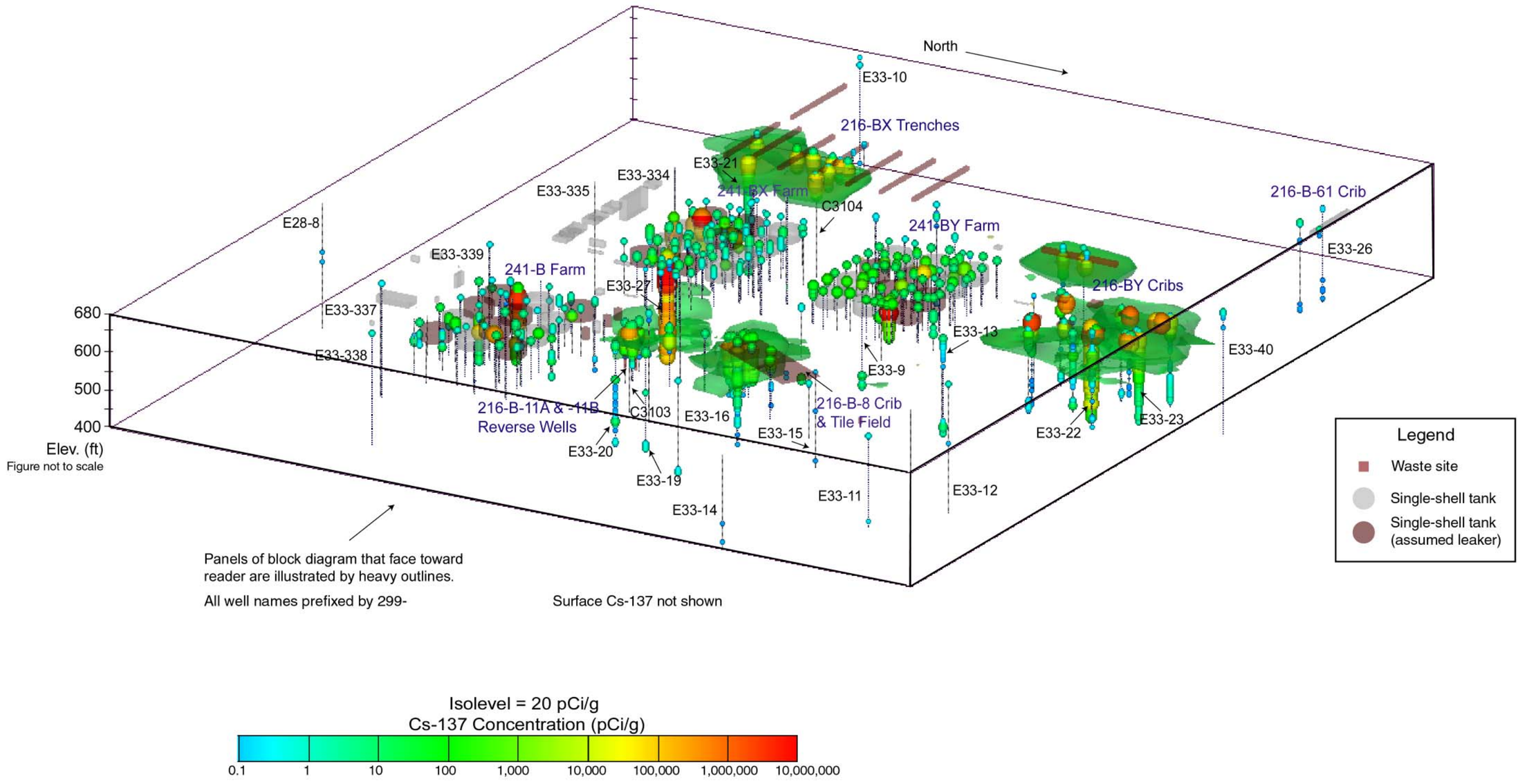


Figure 31. Visualization of ^{137}Cs Subsurface Areas of Contamination, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

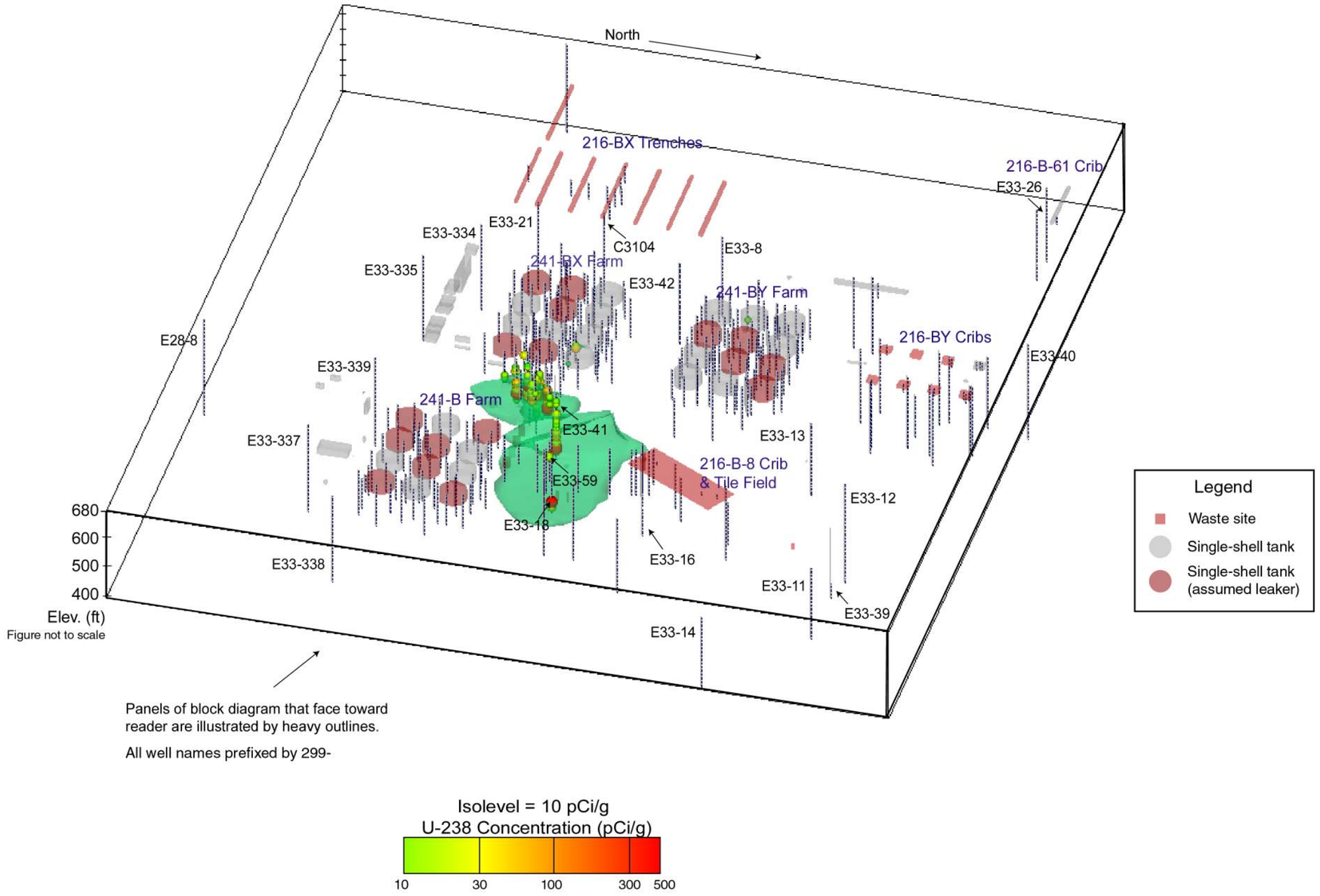


Figure 32. Visualization of ^{238}U Areas of Contamination, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

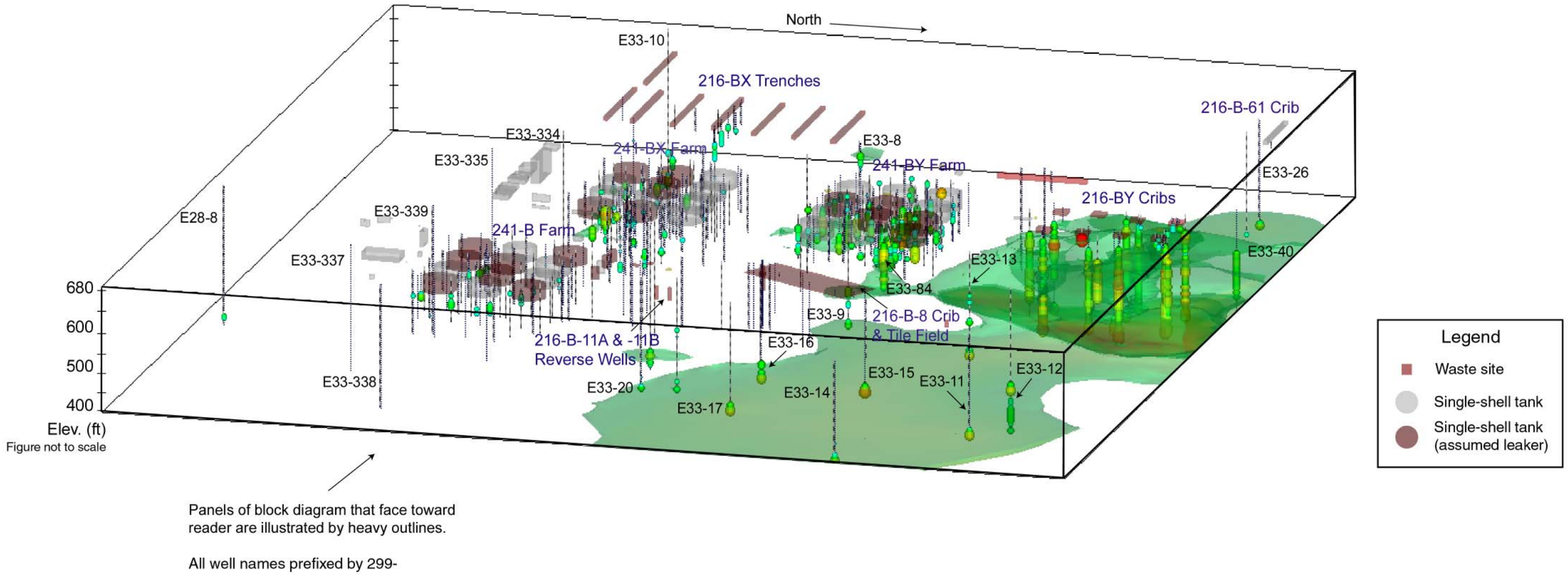


Figure 33. Visualization of ^{60}Co Areas of Contamination B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast in the B-BX-BY WMA Area

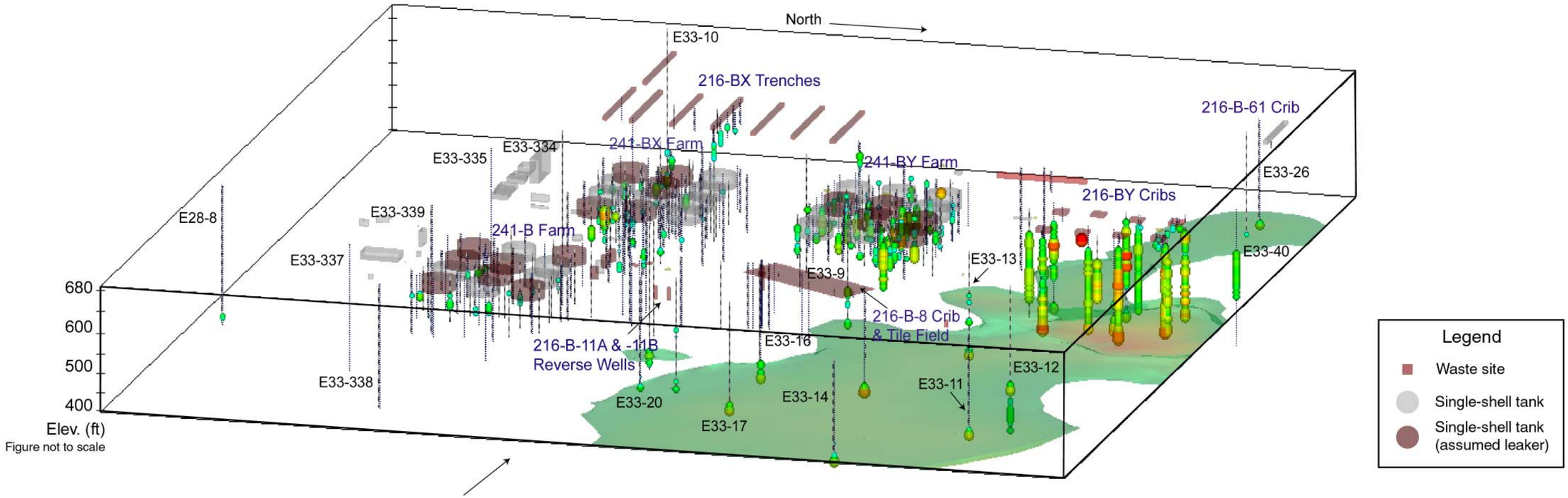


Figure 34. Visualization of Remnant ^{60}Co Contamination near Groundwater, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

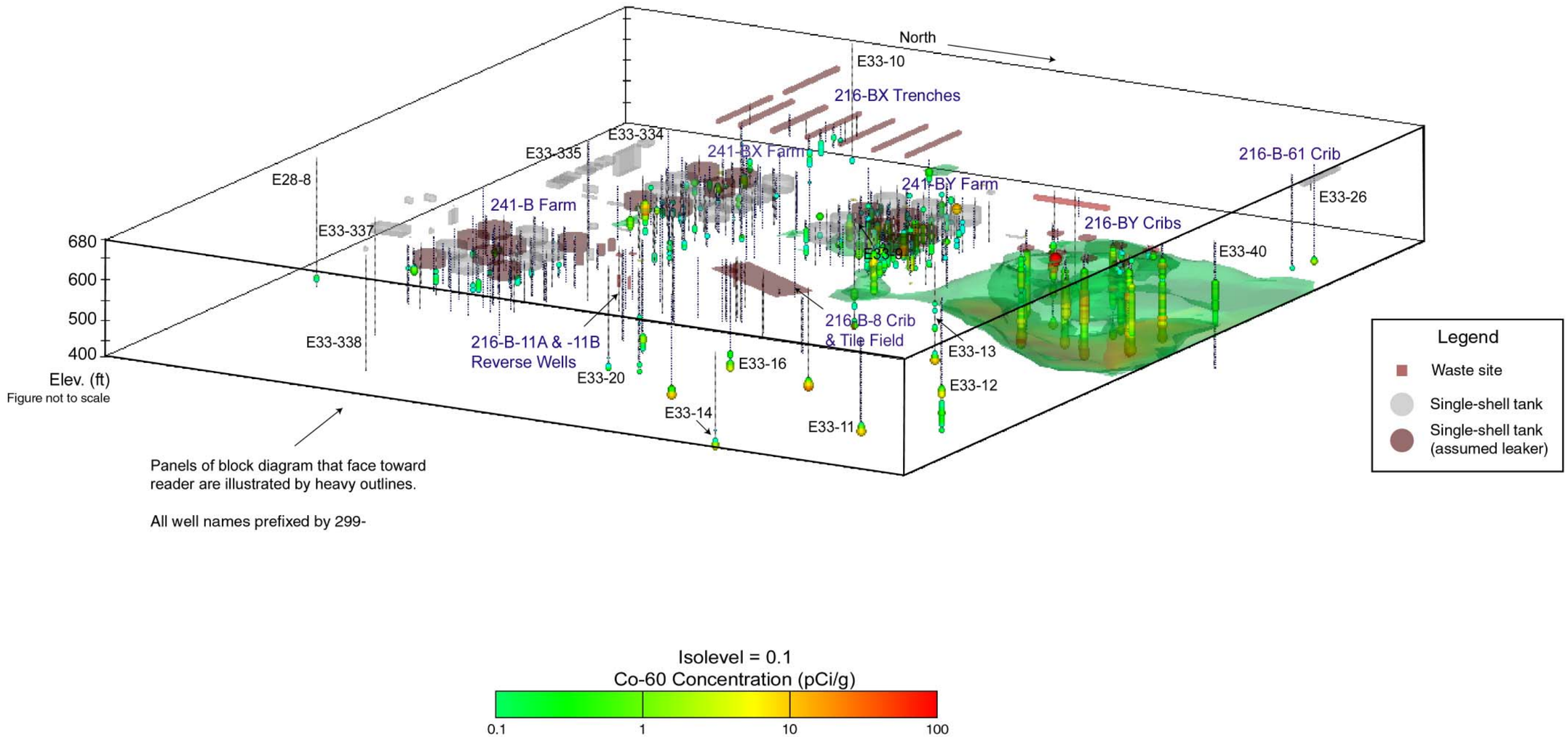


Figure 35. Visualization of ^{60}Co Contamination (Without Remnant ^{60}Co near Groundwater), B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

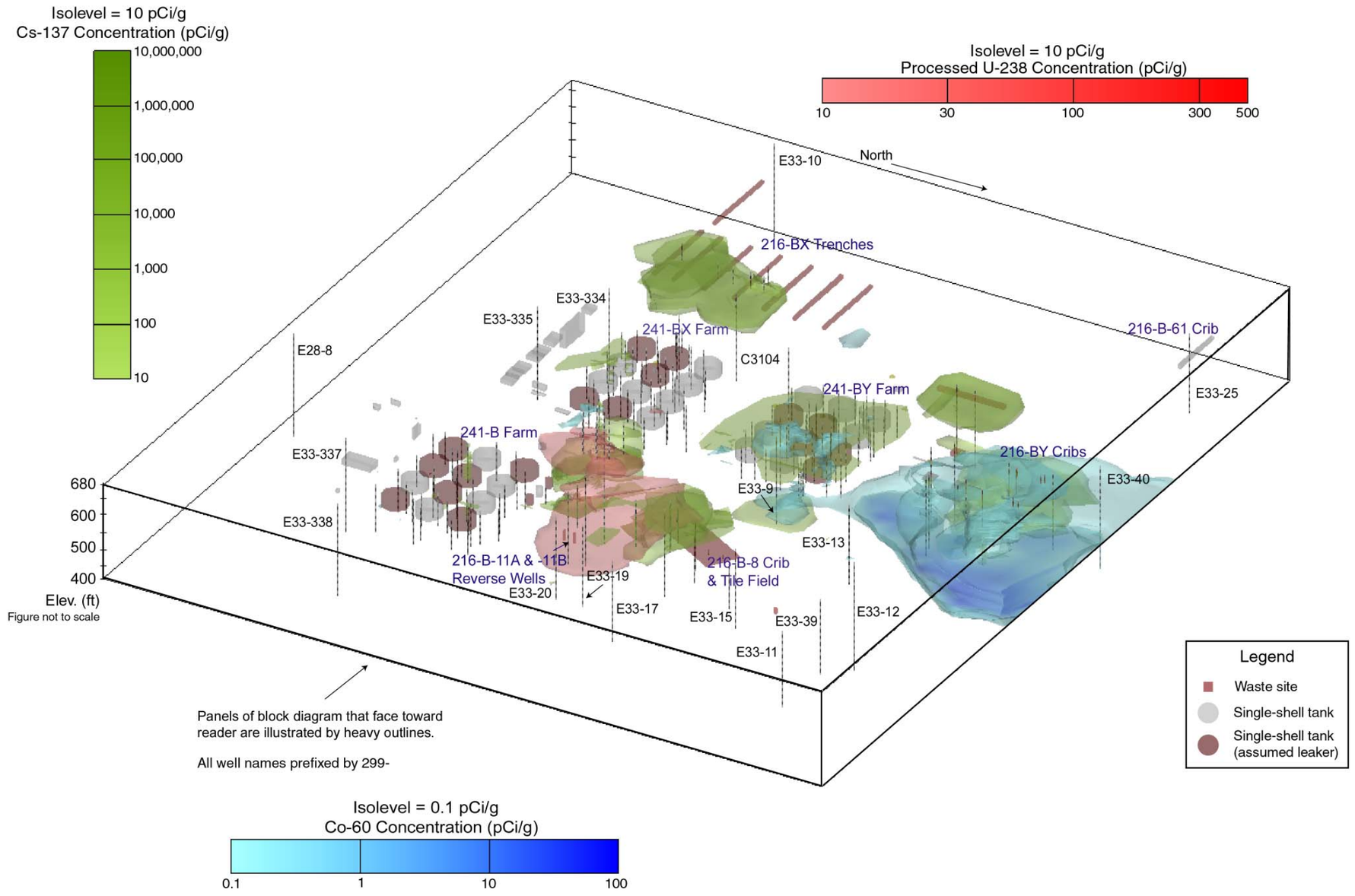
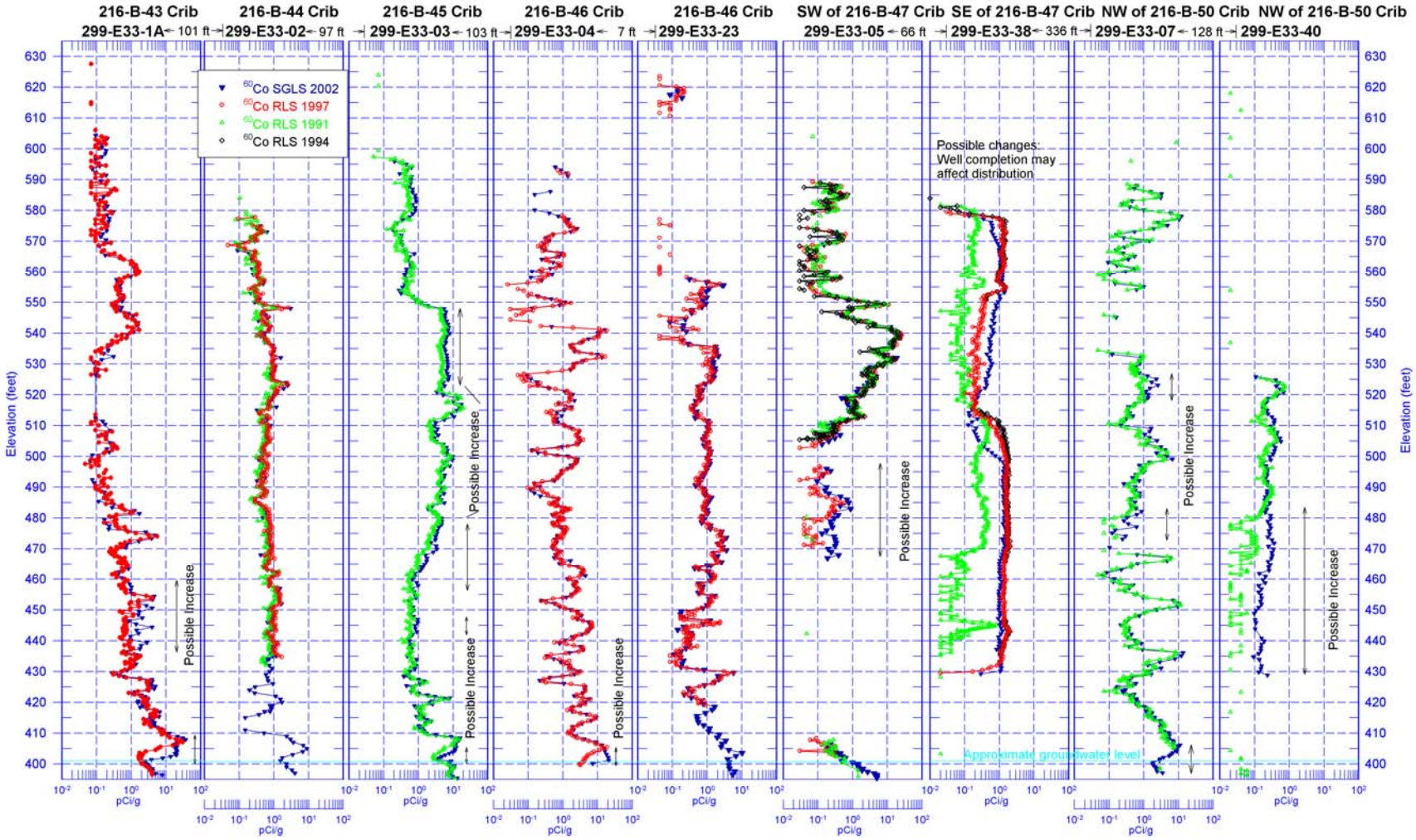
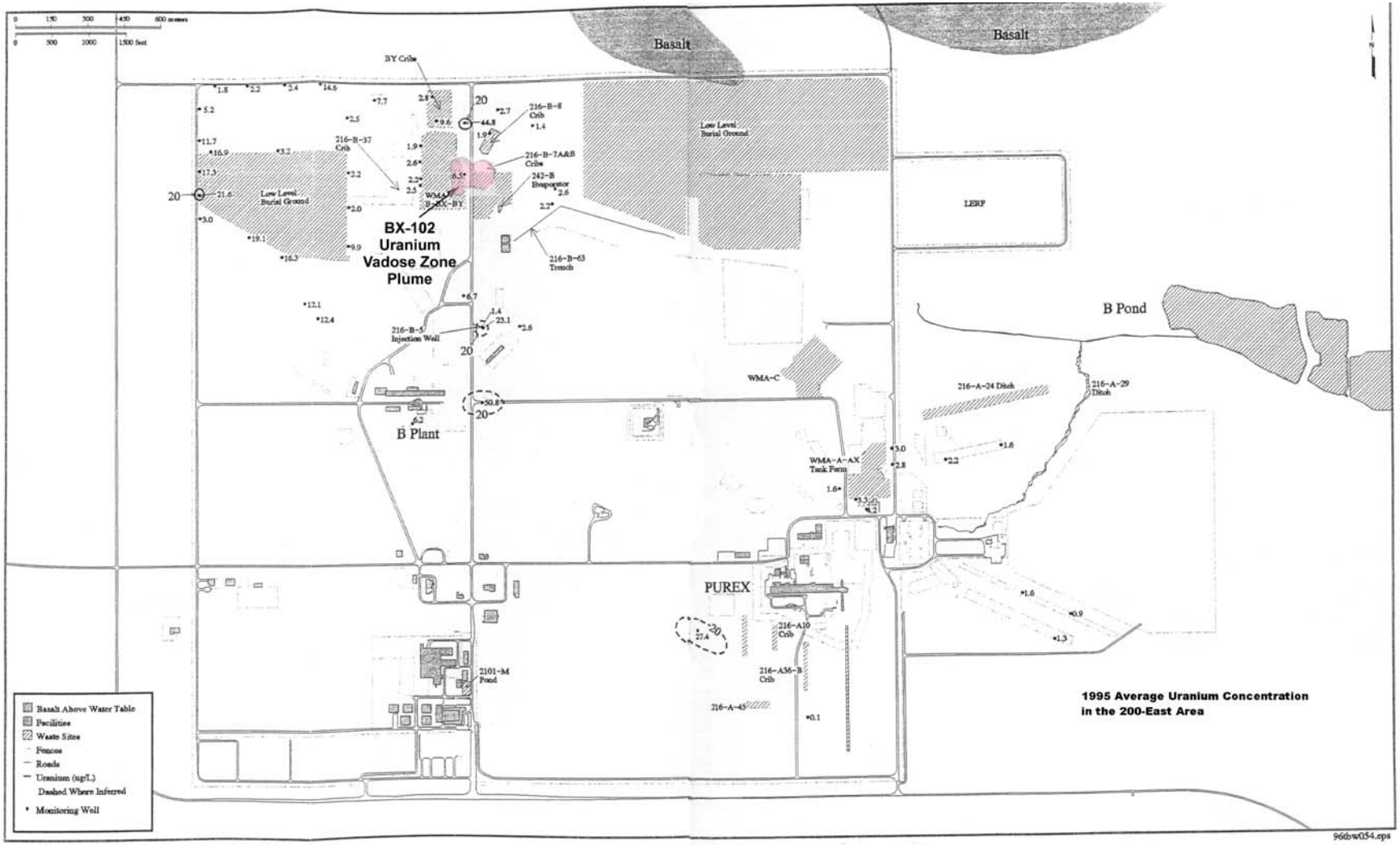


Figure 36. Visualization of the Extent of Vadose Zone Contamination, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast



From DOE (2003a)

Figure 37. Comparisons of ^{60}Co Concentrations between 1992 and 2002 in Nine Boreholes in the Vicinity of the BY Cribs



Modified from PNNL (1996)

Figure 38. 1995 Average Uranium Concentration in Groundwater in the 200 East Area, with the Tank BX-102 Uranium Vadose Zone Plume Superimposed

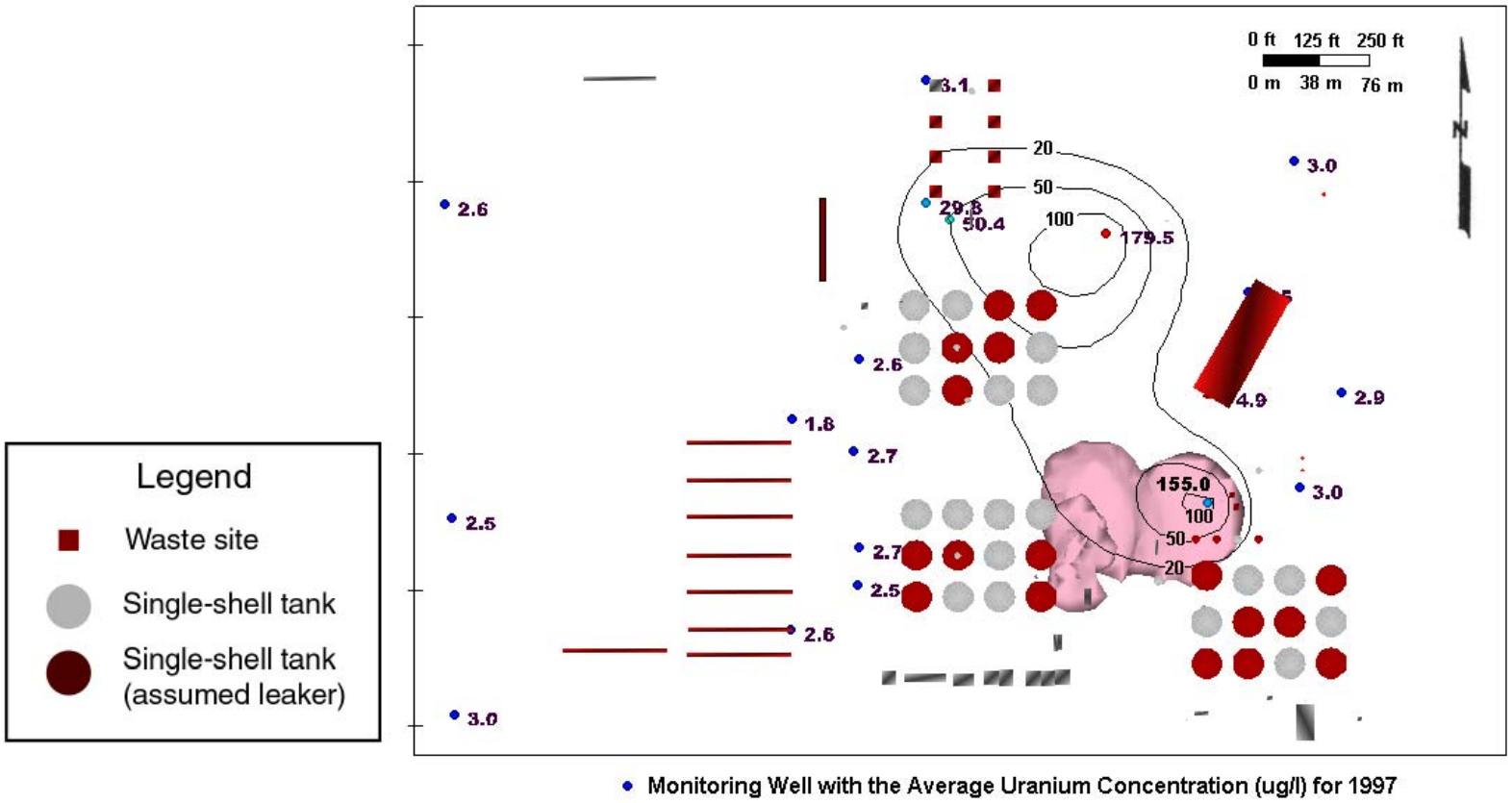


Figure 39. 1997 Average Uranium Concentration in Groundwater in the B-BX-BY WMA Area, with the Tank BX-102 Uranium Vadose Zone Plume Superimposed

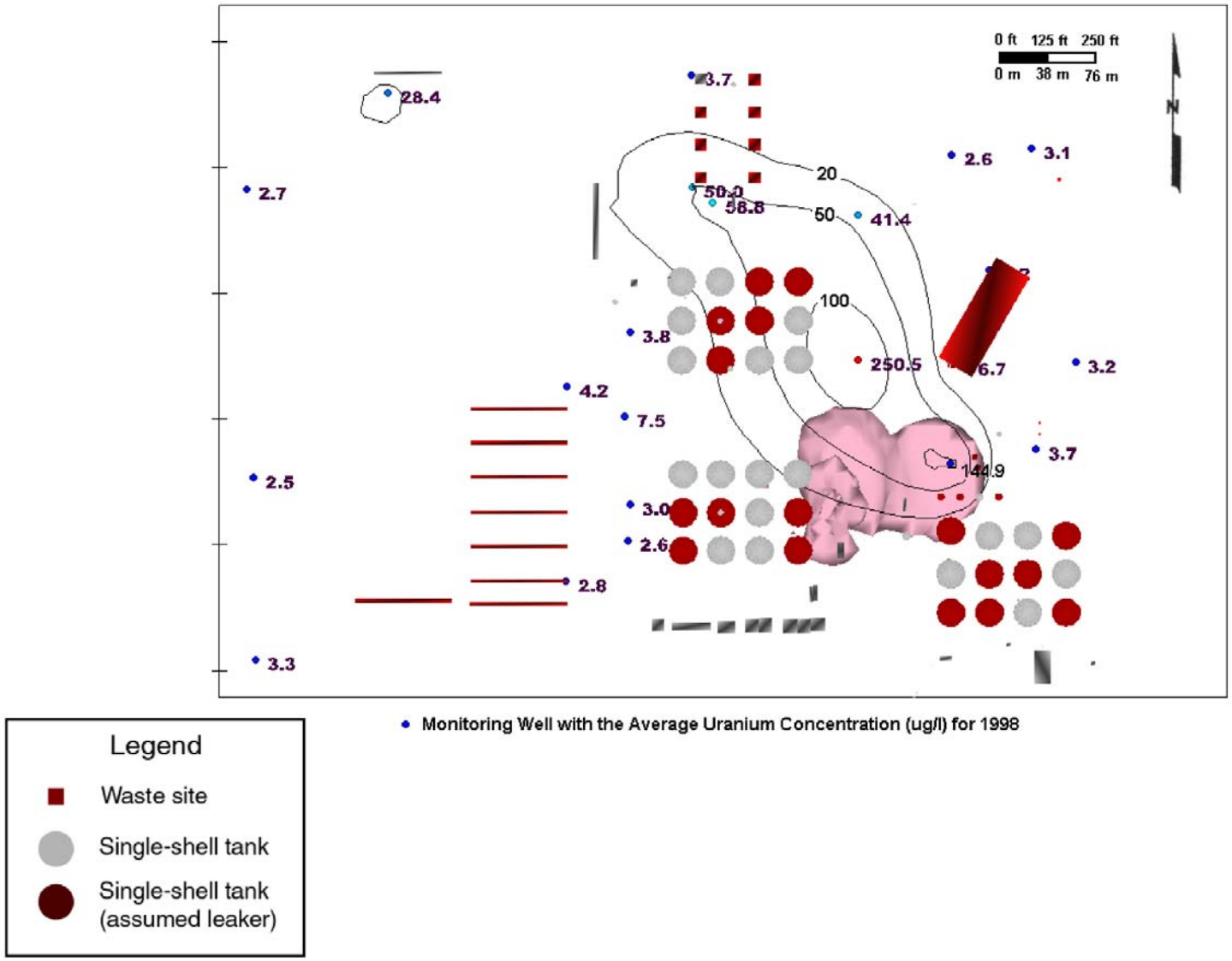
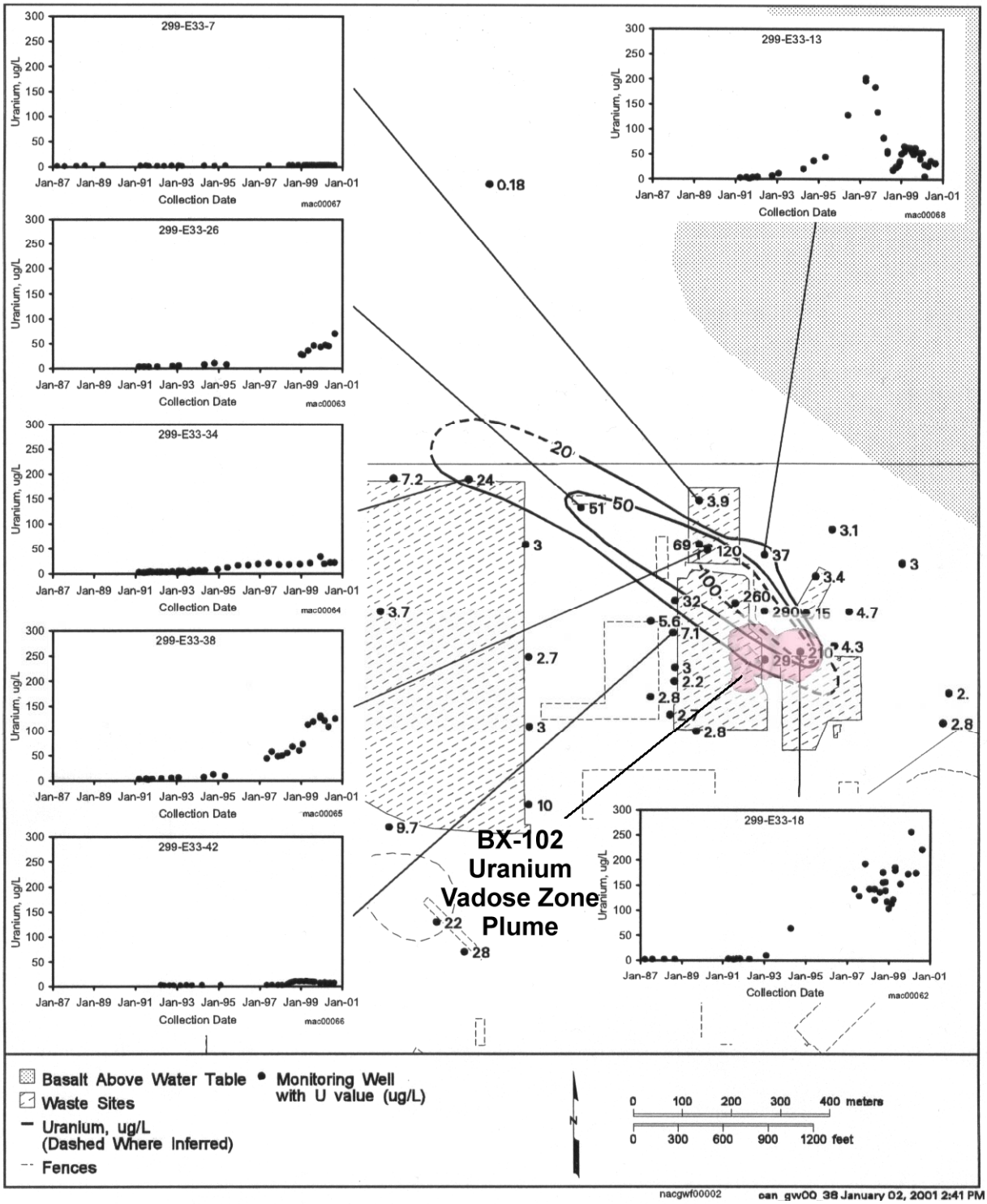


Figure 40. 1998 Average Uranium Concentration in Groundwater in the B-BX-BY WMA Area with the Tank BX-102 Uranium Vadose Zone Plume Superimposed



Modified from PNNL (2001)

Figure 41. 2000 Average Uranium Concentration in Groundwater in the B-BX-BY WMA Area with the Tank BX-102 Uranium Vadose Zone Plume Superimposed

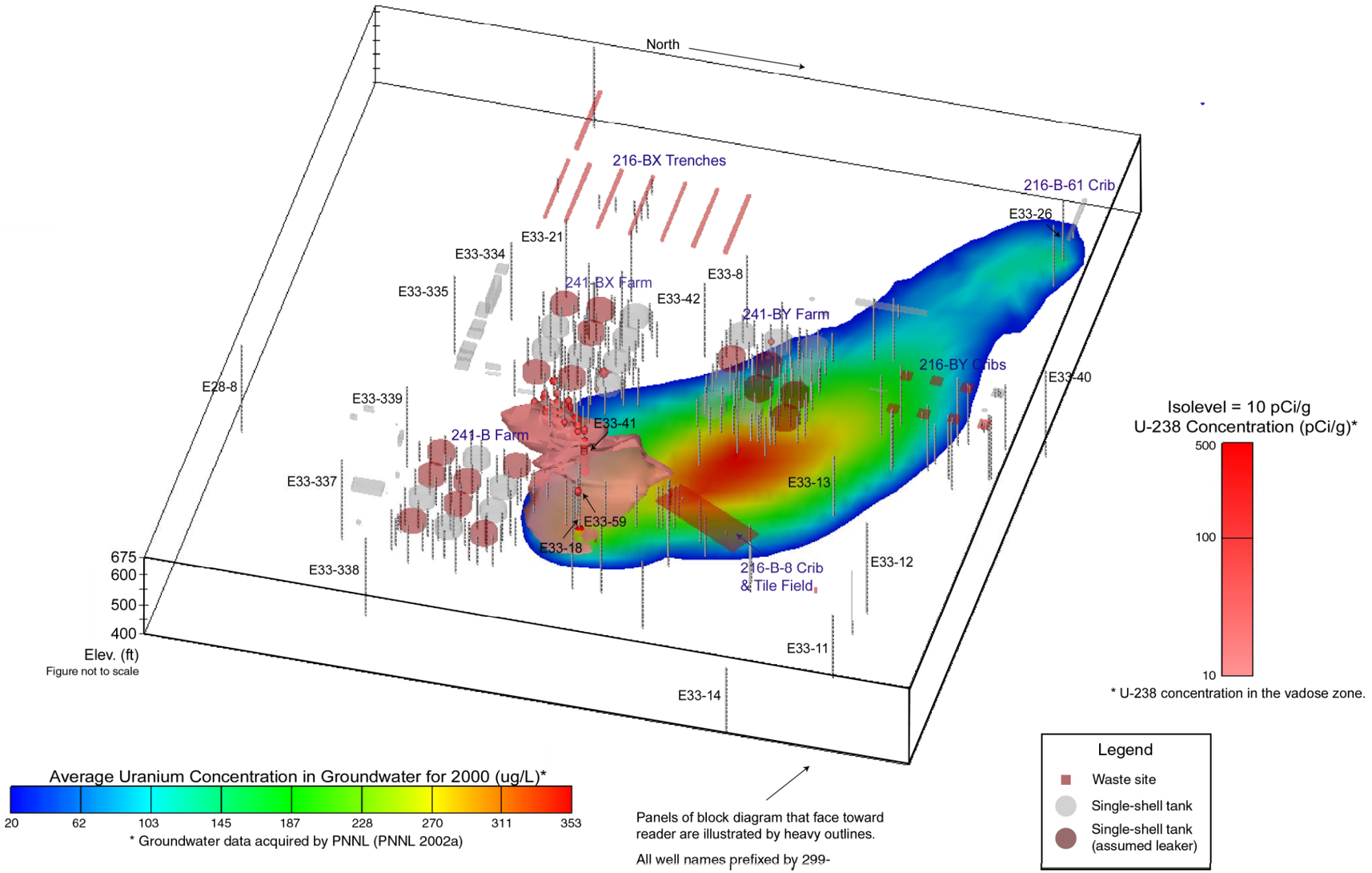


Figure 42. Visualization of the Tank BX-102 Uranium Vadose Zone Plume with the 2000 Average Uranium Concentration in Groundwater

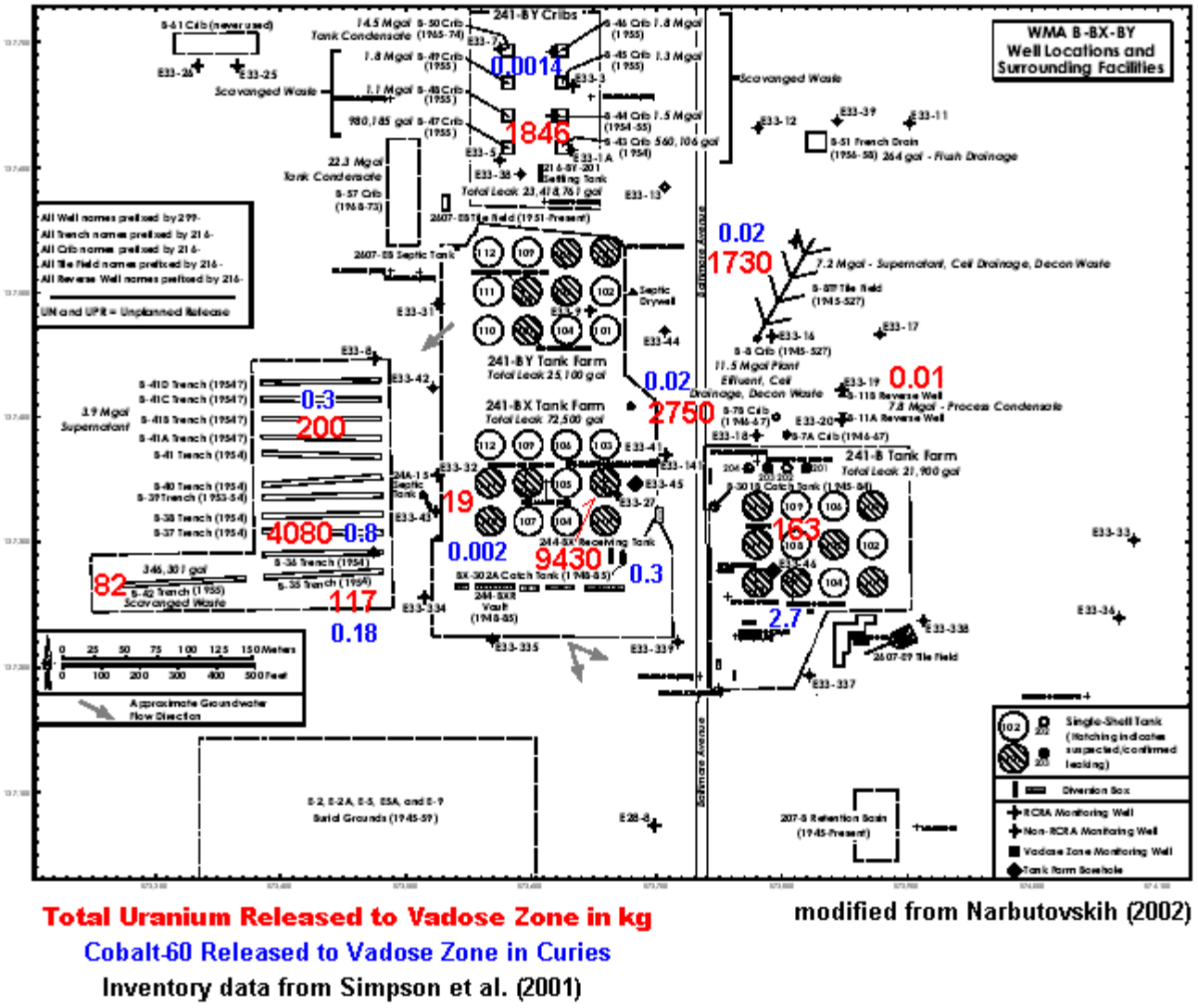
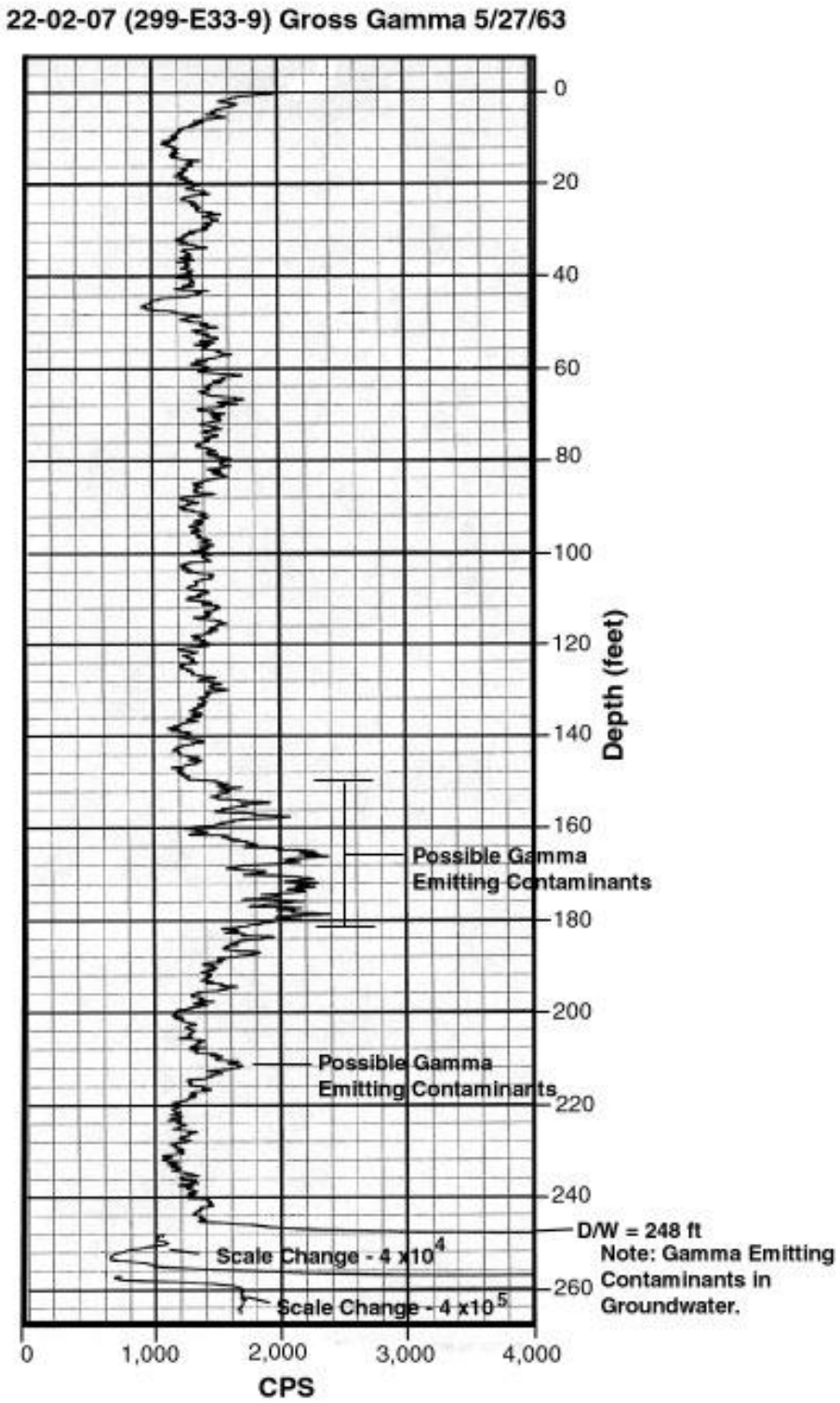


Figure 43. Hanford Soil Inventory Model's Predicted Distribution of Total Uranium Released to the Vadose Zone



From DOE (2000c)

Figure 44. 1963 Gross Gamma Log for Groundwater Well 299-E33-9

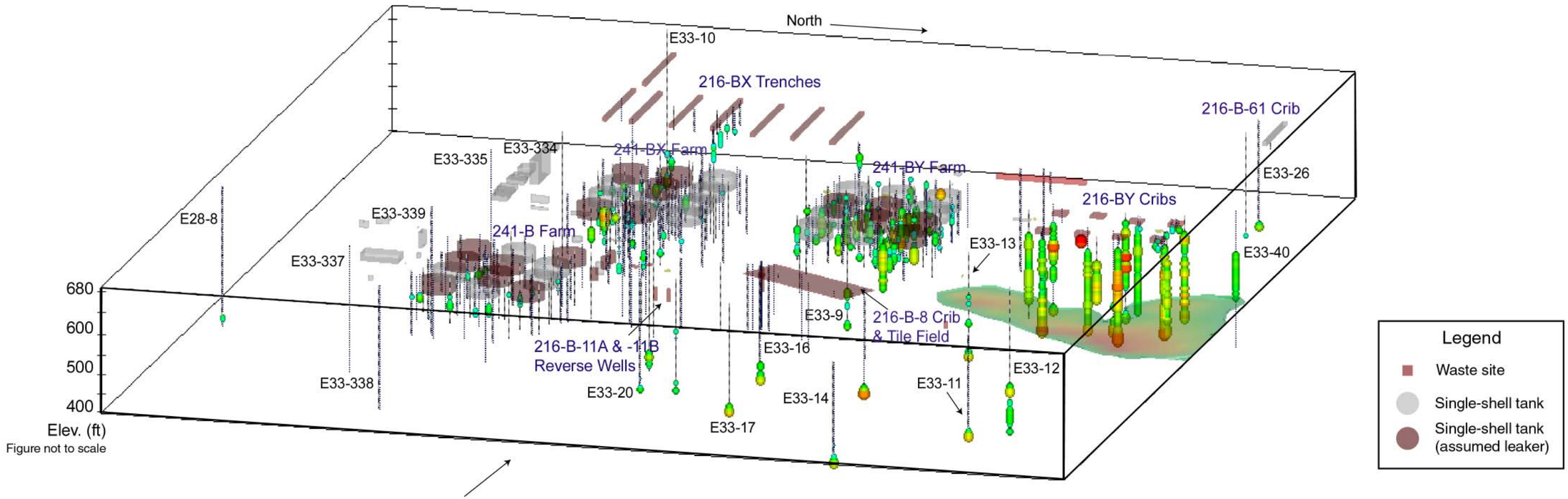


Figure 45. Visualization of ^{60}Co Contamination at the Top of the Cold Creek Unit, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

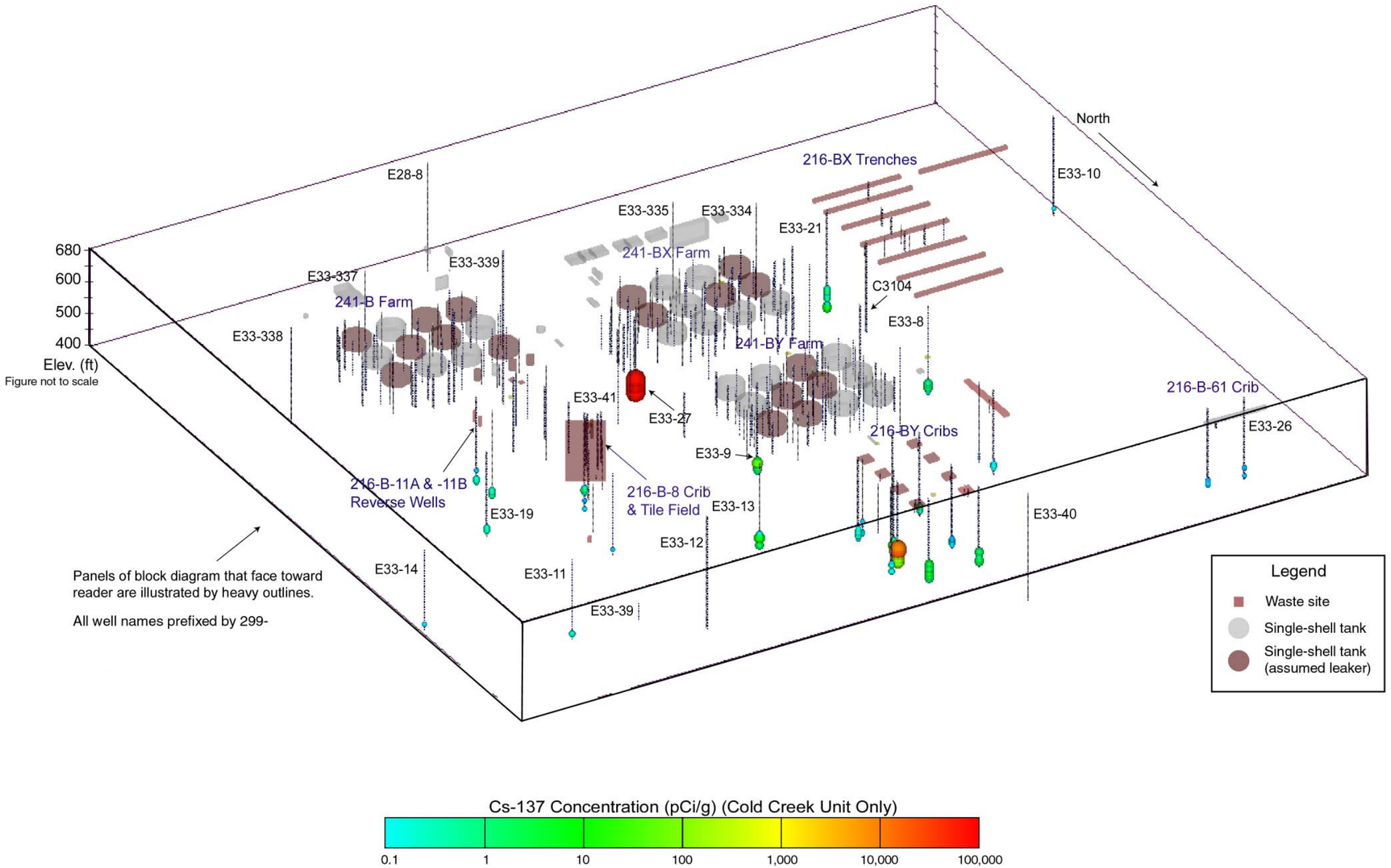


Figure 46. Visualization of ^{137}Cs Contamination in the Cold Creek Unit, B-BX-BY WMA and Adjacent Waste Sites, Viewed from the Northeast

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Appendix A
Reports of Spectral Gamma Ray Logging Results for the B-BX-BY WMA and Adjacent Waste Sites

Table A-1. Reports of Spectral Gamma-Ray Logging Results for the B-BX-BY WMA and Adjacent Waste Sites

Title	Report Number	Issue Date
Waste Site Summary Reports		
216-B-35 to -42 Trenches	GJO-2002-322-TAR	Jul. 2002
216-B-8 Crib and Adjacent Sites	GJO-2002-343-TAR	Aug. 2002
216-B-43 to -50, -57, and -61 Cribs and Adjacent Sites	GJO-2003-458-TAC	Aug. 2003
B Tank Farm		
B Tank Farm Report	GJO-99-113-TAR/ GJO-HAN-28	Mar. 2000
Addendum to the B Tank Farm Report	GJO-99-113-TAR/ GJO-HAN-28	Mar. 2000
B Tank Summary Data Reports		
Tank Summary Data Report for Tank B-101	GJ-HAN-112	Jul. 1998
Tank Summary Data Report for Tank B-102	GJ-HAN-113	Feb. 1999
Tank Summary Data Report for Tank B-103	GJ-HAN-114	Jul. 1998
Tank Summary Data Report for Tank B-104	GJ-HAN-125	Mar. 1999
Tank Summary Data Report for Tank B-105	GJ-HAN-126	Feb. 1999
Tank Summary Data Report for Tank B-106	GJ-HAN-127	Mar. 1999
Tank Summary Data Report for Tank B-107	GJ-HAN-128	Mar. 1999
Tank Summary Data Report for Tank B-108	GJ-HAN-129	Jul. 1999
Tank Summary Data Report for Tank B-109	GJ-HAN-130	May 1999
Tank Summary Data Report for Tank B-110	GJ-HAN-131	Aug. 1999
Tank Summary Data Report for Tank B-111	GJ-HAN-132	Jun. 1999
Tank Summary Data Report for Tank B-112	GJ-HAN-133	Aug. 1999
BX Tank Farm		
BX Tank Farm Report	GJO-98-40-TAR/ GJO-HAN-19	Aug. 1998
Addendum to the BX Tank Farm Report	GJO-98-40-TARA/ GJO-HAN-19	Jul. 2000
BX Tank Summary Data Reports		
Tank Summary Data Report for Tank BX-101	GJ-HAN-95	Jan. 1998
Tank Summary Data Report for Tank BX-102	GJ-HAN-89	Sept. 1997
Tank Summary Data Report for Tank BX-103	GJ-HAN-96	Jan. 1998
Tank Summary Data Report for Tank BX-104	GJ-HAN-97	Jan. 1998
Tank Summary Data Report for Tank BX-105	GJ-HAN-98	Feb. 1998
Tank Summary Data Report for Tank BX-106	GJ-HAN-99	Feb. 1998
Tank Summary Data Report for Tank BX-107	GJ-HAN-100	Mar. 1998
Tank Summary Data Report for Tank BX-108	GJ-HAN-101	Apr. 1998
Tank Summary Data Report for Tank BX-109	GJ-HAN-102	Feb. 1998
Tank Summary Data Report for Tank BX-110	GJ-HAN-103	Apr. 1998
Tank Summary Data Report for Tank BX-111	GJ-HAN-104	Apr. 1998
Tank Summary Data Report for Tank BX-112	GJ-HAN-105	Apr. 1998

Table A-1. Reports of Spectral Gamma-Ray Logging Results for the B-BX-BY WMA and Adjacent Waste Sites

Title	Report Number	Issue Date
BY Tank Farm		
BY Tank Farm Report	GJO-97-2-TAR/ GJO-HAN-6	Feb. 1997
Addendum to the BY Tank Farm Report	GJO-97-2-TARA/ GJO-HAN-6	Sept. 2000
BY Tank Summary Data Reports		
Tank Summary Data Report for Tank BY-101	GJ-HAN-18	Feb. 1996
Tank Summary Data Report for Tank BY-102	GJ-HAN-19	Feb. 1996
Tank Summary Data Report for Tank BY-103	GJ-HAN-20	Feb. 1996
Tank Summary Data Report for Tank BY-104	GJ-HAN-21	Feb. 1996
Tank Summary Data Report for Tank BY-105	GJ-HAN-22	Mar. 1996
Tank Summary Data Report for Tank BY-106	GJ-HAN-23	Mar. 1996
Tank Summary Data Report for Tank BY-107	GJ-HAN-24	Mar. 1996
Tank Summary Data Report for Tank BY-108	GJ-HAN-25	Mar. 1996
Tank Summary Data Report for Tank BY-109	GJ-HAN-26	Apr. 1996
Tank Summary Data Report for Tank BY-110	GJ-HAN-27	Apr. 1996
Tank Summary Data Report for Tank BY-111	GJ-HAN-28	Apr. 1996
Tank Summary Data Report for Tank BY-112	GJ-HAN-29	Apr. 1996

Appendix B
Listing of Boreholes and Wells Used for Geophysical Correlation in the Study of the B-BX-BY WMA and Adjacent Waste Sites

Table B-1. Summary of the Geologic Interpretation of Boreholes and Wells in the B-BX-BY WMA and Adjacent Waste Sites

Borehole Name	Easting	Northing	Reference Elevevation	Backfill	H1	H2	Cold Creek	PPls	TOB
C3340	573472.6	137347.7	664.5	0	10	30	nr[1]	nr	nr
C3341	573455.3	137347.6	665.1	0	10	30	nr	nr	nr
C3342	573437.7	137347.7	665.3	0	11	29	nr	nr	nr
C3343	573420.5	137347.8	665.8	0	10	35	nr	nr	nr
C3344	573403.6	137347.6	666	0	11	39	nr	nr	nr
C3103	573802.6	137385.6	652.8	0	18	37	218	nr	nr
C3104	573471.2	137347.7	662.7	0	8	31	216	220	nr
299-E28-8	573698.1	137074.3	668.5	np[2]	0	36	216	222	298
299-E33-8	573475.3	137447.9	654.3	np	0	28	207	212	257
299-E33-10	573255.5	137258.2	677	np	0	60	202	209	287
299-E33-11	573895.2	137634.6	623.3	np	0	12	193	196	nr
299-E33-12	573780.5	137632.2	626.8	np	2.4	47.4	188	189	237
299-E33-14	573985.6	137567.2	625.4	np	0	19	np	193	229
299-E33-15	573810.3	137540.7	630.6	0	5	22	187	192	238
299-E33-16	573791.7	137465.3	642.1	0	7	27	201	212	251
299-E33-17	573878.5	137467.2	635.1	np	0	27	198	205	244
299-E33-18	573779.2	137386.1	655.2	0	5	41	215	225	274
299-E33-21	573474.4	137293.1	671.7	0	12	45	221	224	280
299-E33-25	573365.2	137681.6	634.3	np	0	25	193	196	235
299-E33-26	573333.3	137681.5	636.1	np	0	52	194	197	239
299-E33-28	573226.4	137375	667.8	np	0	64	196	210	nr
299-E33-29	573227.9	137231.2	674.9	np	0	57	204	213	290
299-E33-31	573525	137491.4	647.7	np	0	50	203	205	255.6
299-E33-32	573524.8	137354	660.2	np	0	40	219	226	271
299-E33-33	574080.1	137301.9	640.7	np	0	37	203	212	252
299-E33-36	574068.5	137240	647.2	np	0	32	209	216	264
299-E33-40	573546.2	137723.1	627.9	np	0	53?	194?	199?	231
299-E33-41	573707.2	137369.9	654.8	np	0	33	215	222	263
299-E33-42	573521	137424.4	657.6	np	0	30	214	216	nr
299-E33-43	573523.2	137325.4	666	np	0	45	225	np	nr
299-E33-44	573706.4	137469.2	641.9	np	0	20	203	208	248
299-E33-45	573677.2	137345.6	658.5	0	9	32	216	225	nr
299-E33-46	573792.6	137278.4	657.3	0	np	40	220	228	nr
299-E33-51	573891.1	137309.8	655.9	0	38	51	nr	nr	nr
299-E33-53	573852.4	137350.3	650.2	0	np	37	nr	nr	nr
299-E33-54	573821.8	137309.9	656.1	0	np	38	nr	nr	nr
299-E33-55	573791.4	137350.4	655	0	38	52	nr	nr	nr
299-E33-56	573780.1	137249.3	659.5	0	np	38	nr	nr	nr
299-E33-58	573797.3	137388.5	654.4	np	0	32	nr	nr	nr
299-E33-59	573797.3	137388.5	654.4	np	0	35	nr	nr	nr
299-E33-61	573690.6	137358.6	655.3	0	6	30	nr	nr	nr
299-E33-62	573659	137298.3	662.4	0	np	36	nr	nr	nr
299-E33-63	573639.6	137399.1	657.1	0	np	35	nr	nr	nr
299-E33-64	573609.2	137358.4	658.7	0	np	42	nr	nr	nr

Table B-1. Summary of the Geologic Interpretation of Boreholes and Wells in the B-BX-BY WMA and Adjacent Waste Sites

Borehole Name	Easting	Northing	Reference Elevevation	Backfill	H1	H2	Cold Creek	PPls	TOB
299-E33-65	573578.6	137399	656.6	0	30	55	nr	nr	nr
299-E33-67	573778.1	137462.4	643.8	0	12	27	nr	nr	nr
299-E33-68	573781.6	137468.5	643.8	0	6	29	nr	nr	nr
299-E33-69	573786	137455.2	643.3	np	0	27	nr	nr	nr
299-E33-70	573775.1	137461.6	643.8	np	0	29	nr	nr	nr
299-E33-71	573780.7	137471.5	643.7	0	10	31	nr	nr	nr
299-E33-72	573789.4	137437.5	644.5	0	12	30	nr	nr	nr
299-E33-73	573791.8	137493.4	635	0	13	23	nr	nr	nr
299-E33-74	573809.6	137502.7	633.3	0	7	23	nr	nr	nr
299-E33-75	573795.5	137412	653.9	np	0	35	nr	nr	nr
299-E33-76	573831.2	137547.4	628.7	0	7	21	nr	nr	nr
299-E33-77	573567.7	137298.2	662.2	0	40	54	nr	nr	nr
299-E33-78	573544.4	137335.7	660.1	0	41	44	nr	nr	nr
299-E33-84	573673.7	137517.4	652.3	0	np	48	nr	nr	nr
299-E33-85	573643.3	137542.5	651	0	48	59	nr	nr	nr
299-E33-86	573615.6	137517.5	653	0	50	62	nr	nr	nr
299-E33-87	573584.3	137486.2	653.2	0	50	53	nr	nr	nr
299-E33-92	573545.1	137335.6	659.9	0	41	43	nr	nr	nr
299-E33-93	573536.7	137336.2	660.3	0	12	43	nr	nr	nr
299-E33-94	573579.8	137531.2	652.4	0	52	57	nr	nr	nr
299-E33-95	573572.2	137518.1	652.5	0	52	58	nr	nr	nr
299-E33-96	573562.9	137516.9	653.2	0	50	56	nr	nr	nr
299-E33-97	573555.2	137521.5	654.3	0	np	49	nr	nr	nr
299-E33-98	573551.9	137530.2	651.9	0	np	48	nr	nr	nr
299-E33-99	573554.2	137542.8	651.4	0	np	48	nr	nr	nr
299-E33-100	573573.8	137541.6	651.8	0	np	50	nr	nr	nr
299-E33-101	573665.9	137511.3	652.7	0	50	58	nr	nr	nr
299-E33-102	573645.8	137501.2	653	0	np	50	nr	nr	nr
299-E33-103	573665.9	137519.3	651.9	0	49	60	nr	nr	nr
299-E33-104	573665.9	137542.5	651	0	48	60	nr	nr	nr
299-E33-105	573645.7	137530.9	651.8	0	49	58	nr	nr	nr
299-E33-107	573635.1	137456.7	654.1	0	47	56	nr	nr	nr
299-E33-108	573615.1	137471.3	655.7	0	49	57	nr	nr	nr
299-E33-109	573634.8	137511.3	652.8	0	49	57	nr	nr	nr
299-E33-110	573634.9	137488.2	653.3	0	50	58	nr	nr	nr
299-E33-111	573614.8	137499.6	652.6	0	49	56	nr	nr	nr
299-E33-112	573634.7	137542.3	651	0	50	57	nr	nr	nr
299-E33-113	573634.8	137519.2	652.5	0	50	57	nr	nr	nr
299-E33-114	573615	137530.7	651.7	0	50	58	nr	nr	nr
299-E33-115	573603.8	137480	652.7	0	48	55	nr	nr	nr
299-E33-116	573603.9	137456.9	653.5	0	np	46	nr	nr	nr
299-E33-117	573583.8	137468.4	653.6	0	48	55	nr	nr	nr
299-E33-118	573603.8	137511.2	652.9	0	49	62	nr	nr	nr
299-E33-119	573603.8	137488	652.4	0	50	55	nr	nr	nr

Table B-1. Summary of the Geologic Interpretation of Boreholes and Wells in the B-BX-BY WMA and Adjacent Waste Sites

Borehole Name	Easting	Northing	Reference Elevevation	Backfill	H1	H2	Cold Creek	PPls	TOB
299-E33-120	573583.8	137501.9	653	0	50	57	nr	nr	nr
299-E33-121	573584.4	137525.3	651.9	0	52	62	nr	nr	nr
299-E33-122	573607.7	137522.5	651.3	0	52	54	nr	nr	nr
299-E33-123	573598.4	137543.6	650.5	0	52	57	nr	nr	nr
299-E33-124	573572.8	137456.9	653.5	0	48	55	nr	nr	nr
299-E33-125	573554.7	137475.7	653	0	48	57	nr	nr	nr
299-E33-126	573572.8	137511.6	653	0	50	58	nr	nr	nr
299-E33-127	573569.4	137486.4	653	0	52	59	nr	nr	nr
299-E33-128	573553.2	137503.5	652.9	0	50	55	nr	nr	nr
299-E33-129	573668.1	137356.7	659.2	0	np	41	nr	nr	nr
299-E33-130	573652.3	137336	659.4	0	np	42	nr	nr	nr
299-E33-131	573652.2	137358.7	658.8	0	np	41	nr	nr	nr
299-E33-132	573679.2	137354.7	659	0	7	33	nr	nr	nr
299-E33-133	573686.2	137344.4	658.2	0	5	37	nr	nr	nr
299-E33-134	573686.3	137332.3	659	0	5	40	nr	nr	nr
299-E33-135	573678.7	137320.1	660	0	np	38	nr	nr	nr
299-E33-138	573698.4	137350.5	655.9	np	0	35	nr	nr	nr
299-E33-139	573698.5	137338.4	656.7	np	0	38	nr	nr	nr
299-E33-141	573698.3	137362.7	655.1	np	0	31	nr	nr	nr
299-E33-142	573686.1	137368.7	656.1	0	6	33	nr	nr	nr
299-E33-143	573661.9	137332.1	660	0	np	41	nr	nr	nr
299-E33-144	573668	137326.1	659.9	0	np	41	nr	nr	nr
299-E33-145	573671.6	137347.5	659.2	0	np	42	nr	nr	nr
299-E33-146	573675.6	137338.3	659.7	0	np	41	nr	nr	nr
299-E33-147	573805.3	137280.9	657.5	0	np	39	nr	nr	nr
299-E33-148	573797.7	137262.6	657.8	0	39	42	nr	nr	nr
299-E33-149	573816	137255	658.2	0	39	53	nr	nr	nr
299-E33-150	573596.6	137362	661.9	0	42	44	nr	nr	nr
299-E33-151	573596.6	137333.7	659.1	0	41	46	nr	nr	nr
299-E33-152	573587.4	137339.3	659.1	0	np	41	nr	nr	nr
299-E33-153	573580.2	137382.8	657.5	0	np	43	nr	nr	nr
299-E33-154	573574	137366	658.2	0	np	42	nr	nr	nr
299-E33-155	573557.8	137368.2	658.5	0	np	42	nr	nr	nr
299-E33-156	573557.7	137387	657.6	0	41	55	nr	nr	nr
299-E33-157	573629.5	137361.7	658.8	0	np	42	nr	nr	nr
299-E33-158	573638	137357	658.7	0	np	41	nr	nr	nr
299-E33-159	573642.2	137347.2	659.1	0	np	41	nr	nr	nr
299-E33-160	573637.8	137338	659.2	0	np	41	nr	nr	nr
299-E33-161	573629.5	137333	659.6	0	41	44	nr	nr	nr
299-E33-162	573617.3	137354.1	658.7	0	np	40	nr	nr	nr
299-E33-163	573629.4	137391.6	657.4	0	np	43	nr	nr	nr
299-E33-164	573637.7	137387.3	657.6	0	np	42	nr	nr	nr
299-E33-165	573637.6	137368.4	658.3	0	np	43	nr	nr	nr
299-E33-166	573617.3	137384.5	660.7	0	np	43	nr	nr	nr

Table B-1. Summary of the Geologic Interpretation of Boreholes and Wells in the B-BX-BY WMA and Adjacent Waste Sites

Borehole Name	Easting	Northing	Reference Elevevation	Backfill	H1	H2	Cold Creek	PPls	TOB
299-E33-167	573576.9	137326.3	659.7	0	40	43	nr	nr	nr
299-E33-169	573558	137307.2	660.2	0	40	45	nr	nr	nr
299-E33-170	573558	137326.2	660	0	40	46	nr	nr	nr
299-E33-171	573576.9	137337.7	659.3	0	np	42	nr	nr	nr
299-E33-172	573560.8	137335.5	659.8	0	42	44	nr	nr	nr
299-E33-173	573579.1	137340.5	658.9	0	np	42	nr	nr	nr
299-E33-174	573555.7	137353.7	659.1	0	np	40	nr	nr	nr
299-E33-175	573558	137356.7	659	0	np	41	nr	nr	nr
299-E33-176	573668.4	137478.3	653.8	0	np	48	nr	nr	nr
299-E33-177	573666	137457	654.2	0	np	48	nr	nr	nr
299-E33-178	573649.8	137459.3	654.4	0	np	47	nr	nr	nr
299-E33-179	573884.9	137298.7	656	0	40	47	nr	nr	nr
299-E33-180	573874.4	137285.9	655.9	0	np	39	nr	nr	nr
299-E33-181	573864.6	137287.3	656.3	0	np	39	nr	nr	nr
299-E33-182	573857.5	137298.5	656.1	0	np	39	nr	nr	nr
299-E33-183	573865.2	137311	655.7	0	np	40	nr	nr	nr
299-E33-184	573880.9	137338.7	654.4	0	40	46	nr	nr	nr
299-E33-185	573885.2	137326.8	655.1	0	40	43	nr	nr	nr
299-E33-186	573870.1	137315.5	655.6	0	np	40	nr	nr	nr
299-E33-187	573858.2	137326.8	654.9	0	np	41	nr	nr	nr
299-E33-188	573865.5	137341.3	654.7	0	40	46	nr	nr	nr
299-E33-189	573850.4	137338.7	654.6	0	np	41	nr	nr	nr
299-E33-190	573854.2	137326.6	655.2	0	np	40	nr	nr	nr
299-E33-191	573842.2	137315.5	657.8	0	np	40	nr	nr	nr
299-E33-192	573833.3	137340.7	654.8	0	np	38	nr	nr	nr
299-E33-193	573824.4	137296.3	656.3	0	np	39	nr	nr	nr
299-E33-194	573815.4	137285.8	657.8	0	np	40	nr	nr	nr
299-E33-195	573800.9	137288.7	656.9	0	np	39	nr	nr	nr
299-E33-196	573796.7	137298.4	656.6	0	np	39	nr	nr	nr
299-E33-197	573820.5	137338	655	0	np	40	nr	nr	nr
299-E33-198	573811.9	137315.5	658.6	0	np	41	nr	nr	nr
299-E33-199	573795.9	137328.8	655.3	0	np	40	nr	nr	nr
299-E33-200	573803.6	137339.4	655.1	0	np	39	nr	nr	nr
299-E33-201	573789.5	137338.4	655.1	0	np	40	nr	nr	nr
299-E33-202	573781.1	137315.5	657.3	0	np	40	nr	nr	nr
299-E33-203	573770.4	137318.9	655.8	0	np	40	nr	nr	nr
299-E33-204	573770.4	137338.4	655.4	0	np	40	nr	nr	nr
299-E33-206	573608.9	137475.1	653.1	0	48	57	nr	nr	nr
299-E33-207	573597.7	137485.5	652.5	0	50	59	nr	nr	nr
299-E33-208	573609.2	137506.3	656.2	0	52	60	nr	nr	nr
299-E33-209	573598.3	137514.6	655.3	0	52	58	nr	nr	nr
299-E33-210	573659.9	137517	652.4	0	50	57	nr	nr	nr
299-E33-211	573671.2	137524.4	651.9	0	np	49	nr	nr	nr
299-E33-212	573822	137273.9	657.5	0	np	39	nr	nr	nr

Table B-1. Summary of the Geologic Interpretation of Boreholes and Wells in the B-BX-BY WMA and Adjacent Waste Sites

Borehole Name	Easting	Northing	Reference Elevevation	Backfill	H1	H2	Cold Creek	PPls	TOB
299-E33-213	573791.6	137273.8	657.3	0	np	39	nr	nr	nr
299-E33-215	573767.2	137267.8	658.4	0	np	40	nr	nr	nr
299-E33-216	573772.8	137256.3	658.8	0	39	42	nr	nr	nr
299-E33-217	573765.2	137298.2	657.5	0	np	40	nr	nr	nr
299-E33-218	573840.4	137284.2	658.5	0	np	40	nr	nr	nr
299-E33-219	573854.7	137267.9	657.8	0	39	44	nr	nr	nr
299-E33-220	573886.9	137268.1	657.1	0	39	48	nr	nr	nr
299-E33-221	573841.3	137252.7	658.5	0	40	59	nr	nr	nr
299-E33-222	573598	137303.1	660.4	0	np	40	nr	nr	nr
299-E33-224	573628.4	137301.4	663.3	0	41	42	nr	nr	nr
299-E33-225	573611.9	137316.2	660.9	0	np	41	nr	nr	nr
299-E33-226	573642.7	137316.2	660.3	0	np	41	nr	nr	nr
299-E33-227	573672.6	137504.4	652.9	0	np	48	nr	nr	nr
299-E33-228	573666.9	137487.9	653.3	0	np	49	nr	nr	nr
299-E33-229	573664.9	137365.2	658.7	0	np	41	nr	nr	nr
299-E33-231	573597.2	137391.3	657.3	0	43	56	nr	nr	nr
299-E33-232	573566.8	137391.4	657.4	0	42	57	nr	nr	nr
299-E33-233	573609.1	137371.6	657.8	0	np	42	nr	nr	nr
299-E33-234	573611.8	137341.7	660.5	0	41	43	nr	nr	nr
299-E33-235	573605.6	137334.8	659.3	0	np	41	nr	nr	nr
299-E33-236	573587.3	137356.7	658.6	0	np	41	nr	nr	nr
299-E33-237	573581.9	137347.2	659	0	np	41	nr	nr	nr
299-E33-238	573658.1	137391.9	657.7	0	np	41	nr	nr	nr
299-E33-239	573672.7	137379.4	658.2	0	42	48	nr	nr	nr
299-E33-240	573673.5	137521.8	652	0	np	47	nr	nr	nr
299-E33-241	573672.7	137511.3	652.4	0	np	47	nr	nr	nr
299-E33-242	573653.5	137516.6	654.3	0	49	60	nr	nr	nr
299-E33-243	573646.2	137539.4	651.3	0	50	57	nr	nr	nr
299-E33-244	573648.4	137521	654	0	49	59	nr	nr	nr
299-E33-245	573673	137469.2	654.3	0	49	62	nr	nr	nr
299-E33-246	573645.7	137472.5	654	0	48	57	nr	nr	nr
299-E33-248	573619.1	137457.2	655	0	48	57	nr	nr	nr
299-E33-249	573623.3	137481.4	653.5	0	49	56	nr	nr	nr
299-E33-250	573620	137542.5	650.9	0	50	56	nr	nr	nr
299-E33-251	573588	137456.9	654.1	0	47	56	nr	nr	nr
299-E33-254	573558.7	137456.9	653.3	0	48	59	nr	nr	nr
299-E33-255	573550.8	137465.4	653.2	0	48	58	nr	nr	nr
299-E33-257	573607.9	137387.9	657.6	0	np	41	nr	nr	nr
299-E33-258	573586.7	137369.2	657.9	0	42	43	nr	nr	nr
299-E33-259	573608.9	137538.6	651	0	51	59	nr	nr	nr
299-E33-260	573592.5	137517.8	651.8	0	51	56	nr	nr	nr
299-E33-261	573881.7	137278.4	656.6	0	nr	39	nr	nr	nr
299-E33-262	573881.3	137255.2	657.3	0	39	47	nr	nr	nr
299-E33-263	573862.7	137255.2	658.1	0	39	52	nr	nr	nr

Table B-1. Summary of the Geologic Interpretation of Boreholes and Wells in the B-BX-BY WMA and Adjacent Waste Sites

Borehole Name	Easting	Northing	Reference Elevevation	Backfill	H1	H2	Cold Creek	PPls	TOB
299-E33-264	573862.6	137278.1	656.8	0	39	46	nr	nr	nr
299-E33-274	573875.4	137256	657.2	0	39	48	nr	nr	nr
299-E33-286	573426	137272.5	672.6	2	4	41	nr	nr	nr
299-E33-287	573436.5	137311.1	670.2	np	0	40	nr	nr	nr
299-E33-288	573436.5	137325	669.4	np	0	36	nr	nr	nr
299-E33-289	573436.5	137340.7	667.7	np	0	34	nr	nr	nr
299-E33-290	573436.5	137353	666.2	np	0	33	nr	nr	nr
299-E33-334	573514.7	137256.4	667	np	0	45	220	221	281
299-E33-335	573568.4	137222.2	667.4	np	0	52	217	223	281
299-E33-337	573821.8	137193.9	662.7	np	0	56	212	213	281
299-E33-338	573912.1	137238.2	657	np	0	52	213	223	271
299-E33-339	573716.9	137221.5	663.7	0	6	55	np	215	279

[1] nr – not reached
[2] np – not present

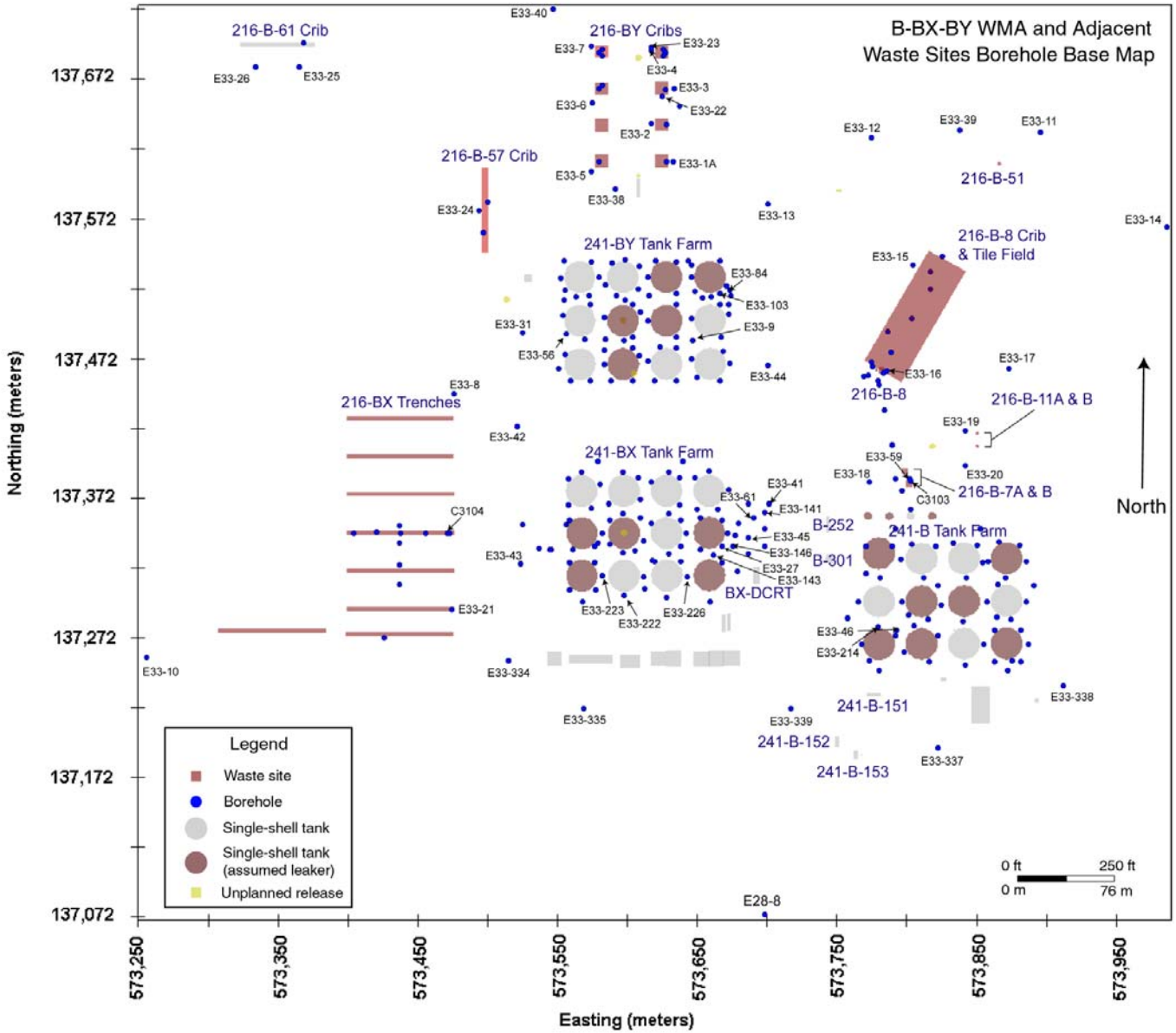

Figure B-1. Borehole Base Map for the B-BX-BY WMA and Adjacent Waste Sites

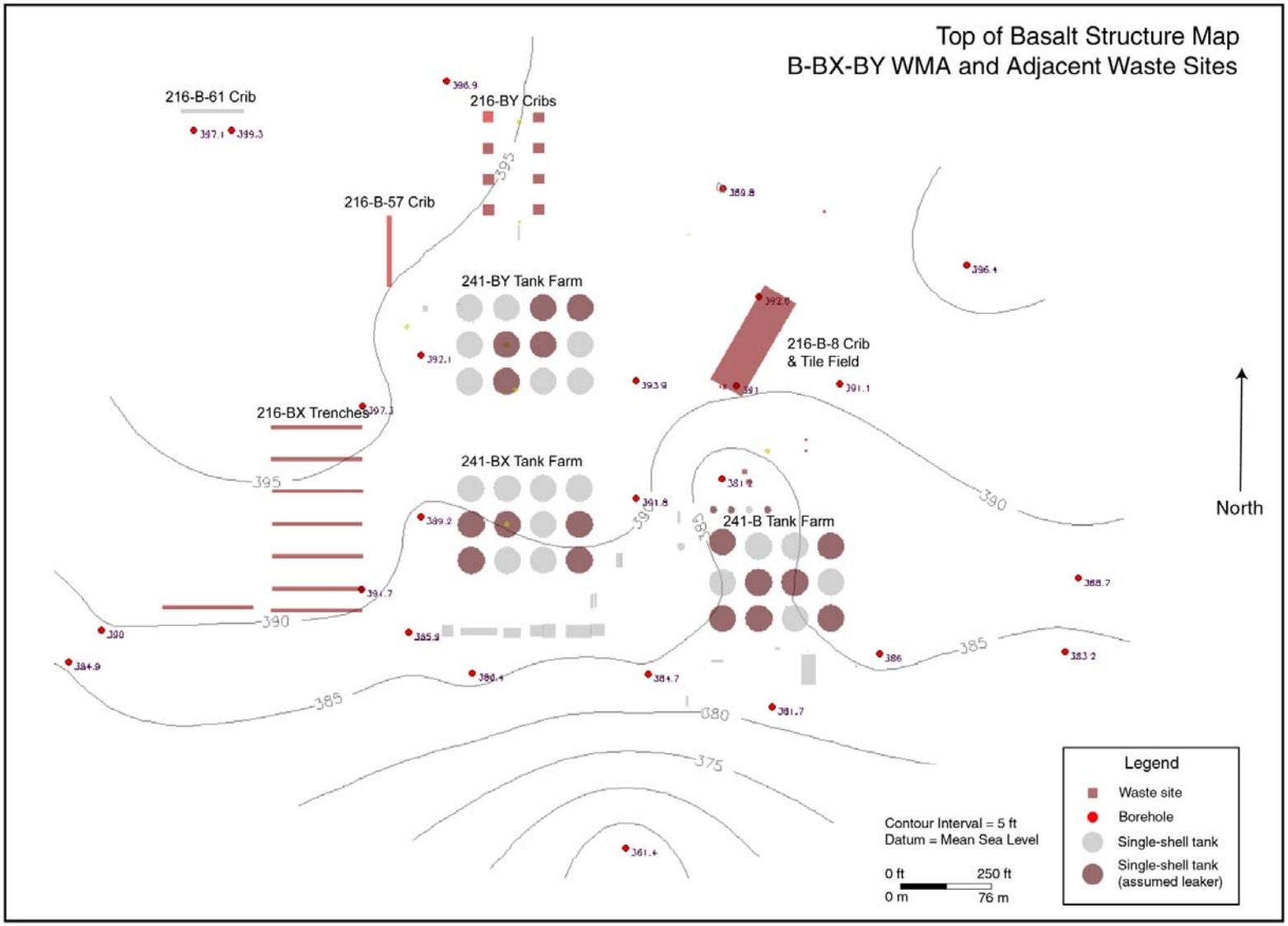

Figure B-2. Top of Basalt Structure Map, B-BX-BY WMA and Adjacent Waste Sites

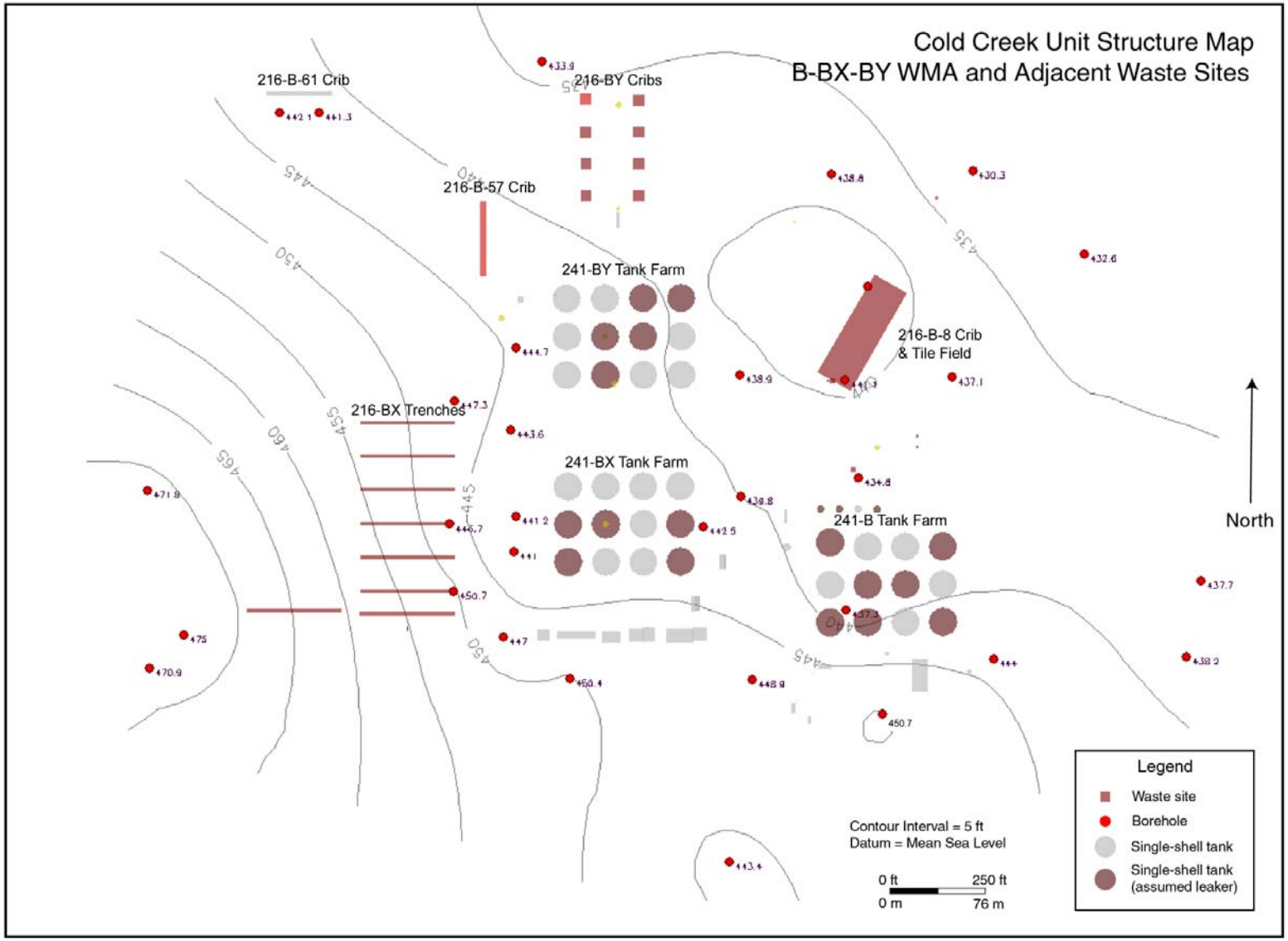

Figure B-3. Cold Creek Unit Structure Map, B-BX-BY WMA and Adjacent Waste Sites

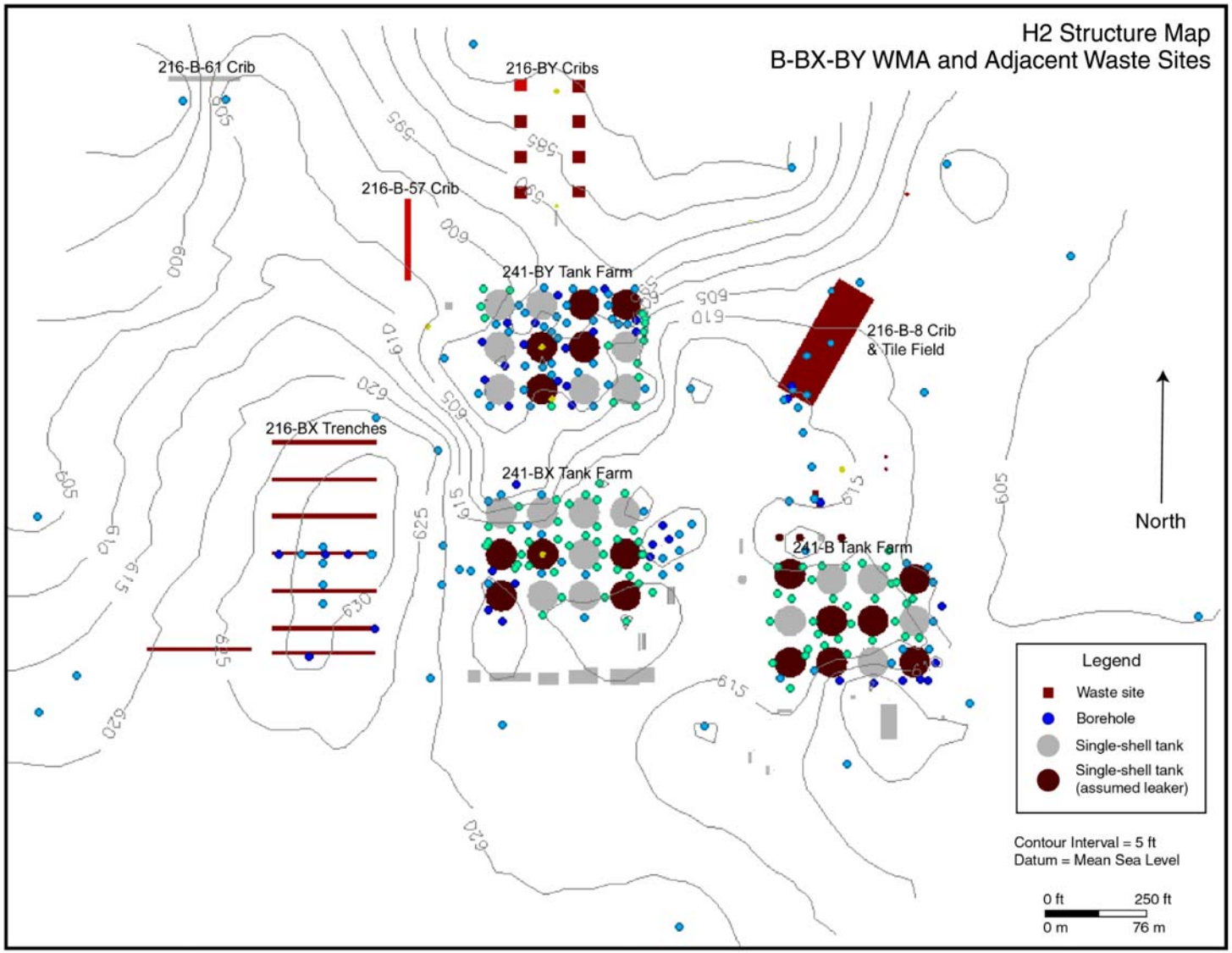

Figure B-4. H2 Structure Map, B-BX-BY WMA and Adjacent Waste Sites

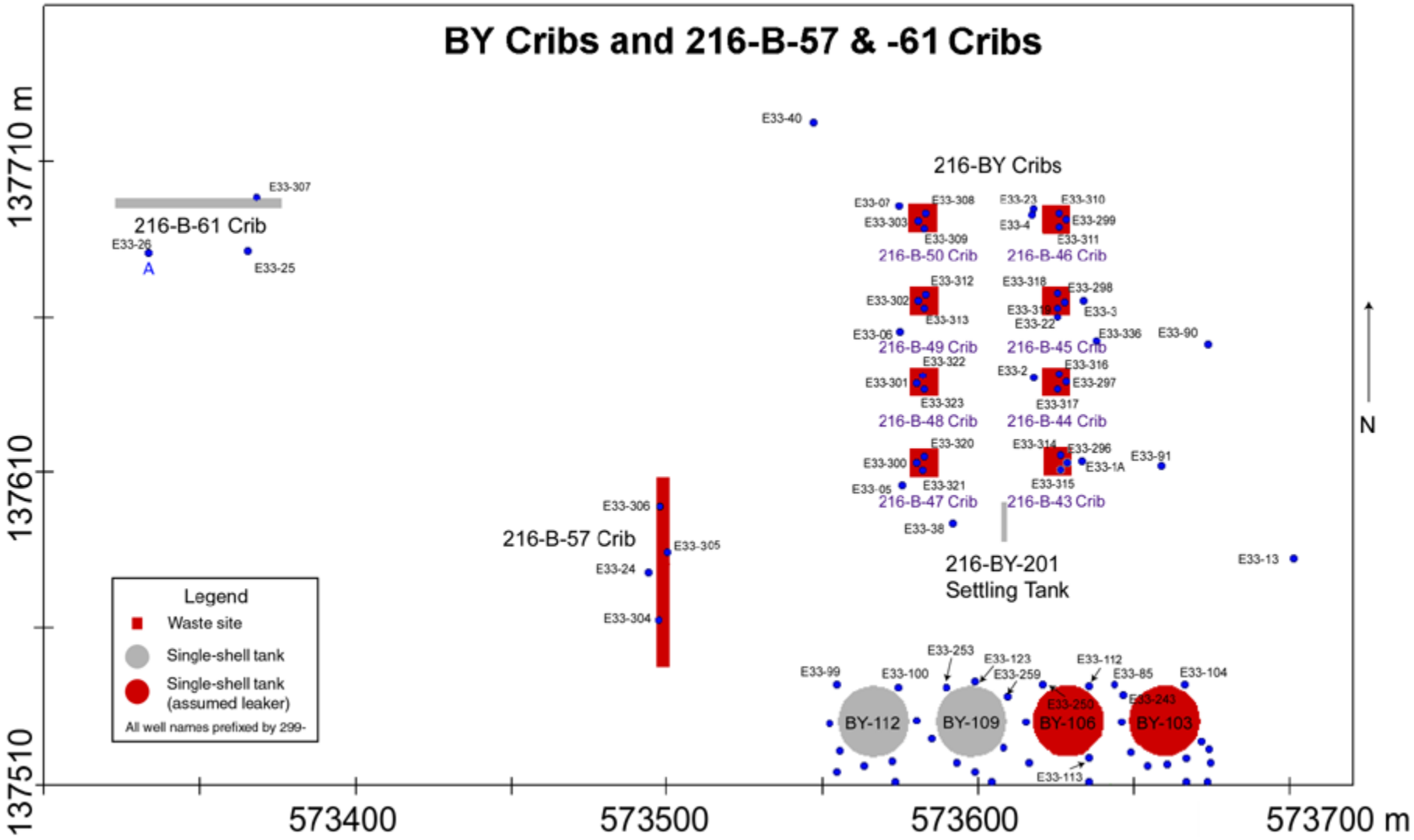

Figure B-5 Borehole Basemap for the BY Cribs and 216-B-57 & -61 Cribs